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## THE BELLEVILLE BOILER.


BY L. FAUVEAU, ENGINEER.

[Translated from the French, for publication, by L. PIAUD, Marine Engineer.]


### PRELIMINARY REMARKS.

It seems necessary, at the beginning of this article, to enumerate the principal plants fitted with Belleville boilers, because the description of a particular type of boiler is more interesting as that system is more widely spread, and it is desirable to show that, on this account alone, the article is worthy the reader's attention.

Belleville boilers have been applied to two different orders of work: marine installations on sea-going ships and stationary installations on land for industrial purposes.

The former is the more important, on account of the considerable powers represented in each case, but the other is equally interesting, if the diversity of the duties fulfilled by these boilers be considered; each completes the other in showing the ability of the Belleville boiler to meet all requirements connected with the employment of steam.

I.—BELLEVILLE BOILERS FITTED ON BOARD SEA-GOING SHIPS.

| | Date of the first adoption. | Number of ships. | Total Horsepower. |
|---|---|---|---|
| French Navy | 1879 | 46 | 448,560 |
| British Navy | 1893 | 61 | 966,300 |
| Russian Navy | 1886 | 35 | 243,200 |
| Russian Volunteer Fleet | 1894 | 3 | 44,500 |
| Japanese Navy | 1896 | 10 | 122,700 |
| Austrian Navy | 1895 | 5 | 56,700 |
| Chilian Navy | 1896 | 4 | 26,500 |
| Argentine Navy | 1896 | 3 | 19,000 |
| Italian Navy | 1898 | 4 | 70,500 |
| Spanish Navy | 1898 | 1 | 11,000 |
| Total | | 172 | 2,008,960 |
| Cie des Messageries Maritimes | 1884 | 14 | 87,600 |
| Western Railway Co. | 1893 | 8 | 18,500 |
| General Transatlantic Co. | 1900 | 1 | 1,500 |
| Total | | 23 | 107,600 |

Besides the above applications, numerous launches, tug boats, fisheries patrols, yachts, dredgers, &c., also service boats in the French and other Navies have been supplied with Belleville boilers.

II.—BELLEVILLE BOILERS.—INDUSTRIAL PLANTS ON LAND.

These applications are so numerous that not all can be mentioned here. Only the most important are given in each branch of industry. (See table opposite.)

It must be further mentioned that numerous boilers have been fitted in various works of a lesser importance than those tabulated: cellulose, glass and paper manufactories, printing shops and mechanical works, as well as in public or private hotels, hospitals and offices; in a word, wherever steam is needed to produce power, light or heating.

Last of all, since 1884, a new type of Belleville boiler has been designed with the purpose of utilizing the waste heat from coke furnaces, and twelve of these plants have already been fitted up, amounting to 66 boilers with a total evaporation of 190 tons of steam per hour.

| Names of establishments. | Year of order. | Number of plants. | Number of boilers. | Total steam production per hour (in tons). |
|---|---|---|---|---|
| Ministry of War: Weapon and powder manufactories, schools, fortresses, military balloons | 1886–1902 | 23 | 113 | ..... |
| Ministry of Marine: Dock yards, submarine-boat equipping stations, lighting plants | 1881–1902 | 11 | 41 | ..... |
| Ministry of Finance: Tobacco and match manufactories | 1879–1903 | 22 | 70 | ..... |
| Ministry of Commerce, Post and Telegraph: Schools, post and telegraph main building, printing offices | 1883–1899 | 7 | 21 | ..... |
| Ministry of Interior: Printing shops, public buildings, prisons | 1868–1899 | 3 | 11 | ..... |
| Colonial Office: Department of ordnance | 1897–1899 | 2 | 3 | ..... |
| Eastern Railway Co.: Heating and lighting plants | ..... | 3 | 12 | 15.06 |
| Western Railway Co.: Workshops, lighting plants, terminus hotel | ..... | 4 | 14 | 17.55 |
| Paris-Orleans Railway Co.: Workshops | ..... | 3 | 6 | 7.65 |
| Northern Railway Co.: Lighting plant | ..... | 1 | 2 | 3.7 |
| P. L. M. Railway Co. | ..... | 2 | 3 | 2.0 |
| Austro-Hungarian State Railway: Workshops, lighting of stations | ..... | 3 | 12 | 20.7 |
| Metallurgy and Mines | 1868–1902 | 25 | 273 | 489.15 |
| City of Paris: Water service | 1882–1901 | 6 | 13 | 16.025 |
| Soap and candle manufactory, A. Fournier, Marseilles | 1881–1903 | 1 | 28 | 72.23 |
| Danish Government: Lighthouses | 1884–1899 | 13 | 25 | ..... |
| Edison Continental Co., Paris | 1885–1901 | 6 | 48 | 131.72 |
| Société anonyme d'Eclairage et de Force par l'Electricité, Paris | 1889–1899 | 4 | 19 | 36.7 |
| Société du "Petit Journal," Paris | 1867–1896 | 1 | 6 | 7.85 |
| Sugar refinery, "Lebaudy Bros." Paris | 1880–1900 | 1 | 22 | 50.9 |
| Cloth manufactories, dyeing and stiffening, weaving, &c., at Roubaix, Lille, Tourcoing, Reims | 1883–1902 | 24 | 59 | 158.0 |
| Theaters in Paris, Rouen, Cabourg, Fiume, Lisbon | ..... | 8 | .... | 33.0 |
| Central electric stations in France, Spain, Russia, Brazil, Argentine Republic | ..... | 40 | .... | 600.0 |
| Great stores in Paris, Lyons, Marseilles, Lille, Nancy, Bayonne | ..... | 12 | .... | 64.0 |

The object of this article is not only to describe the present Belleville boiler, but also to explain the various stages through which it passed until it attained those qualities that make it universally appreciated today and contribute to its general employment.

This history of advance will be found interesting from many points of view. While it is an homage to the high intelligence, spirit of invention and enterprise of its creator, it, moreover, by simply setting forth the improvements in each successive type, overthrows the statements purposely spread about, which still attribute to the latest types defects which have been corrected for many years.

To quote one single example of this, it is not uncommon to hear defects still criticised as inherent to the present system which belonged to the *express boiler*, designed about 1850, and on account of which defects it was abandoned a few years later.

This history will also reply finally and categorically to the remarks of some misinformed critics who daily propose to cure imaginary defects by adopting special features which have already existed in former types and have had to be finally rejected.

It will be necessary, however, to answer in a particular way the criticism of the British Boiler Committee appointed by the Admirality to examine the question of marine boilers. This criticism was so widely published and so audaciously used that it cannot be overlooked, and must be demonstrated to be valueless. It is, in fact, beaten down by the conclusive fact that, at present, sixty-one British warships, representing 966,300 horse-power, are fitted with Belleville boilers and achieve performances unheard of up to the present day.

It is impossible, however, to cherish the hope of disarming all criticism. The steadily increasing success of these boilers, from their very beginning, especially conspicuous during the past fifteen years, could not continue without raising sanguine rivalry. Many inventors sprang up to take advantage of the long and arduous works of the creator of water-tube boilers, and each needed arguments to show that his own invention was superior to that of the originator. Hence more or less justified reproaches, always exaggerated, were brought to the whole world's attention

by every advertising means. Such an inexhaustible spring of misrepresentation cannot be choked, but, to those who unconsciously drank from it, is now offered the means for acknowledging their mistake.

This history will follow the chronological order shown by the patents taken in connection with each modification, from the initial coil, in which the first Belleville boiler consisted, to the present type.

In describing each of the successive types, the improvements embodied therein will be pointed out, and the defects the type was intended to suppress, according to the practical experience gained. The principal applications of each type will also be quoted, and it will be interesting to recognize the long and excellent services rendered by certain comparatively imperfect models.

Marine installations will be given more attention than others, on account of their importance, but the principal industrial installations will not be passed over in silence. It must not be forgotten that, while the Belleville boilers actually in service on sea-going ships supply steam for over two millions of horsepower, they are also supplying over 450,000 horsepower in the most diversified industries.

Theories on the formation of steam, circulation of water in boilers, or on other similar subjects are purposely omitted, because of their certainty to cause useless controversy. On the other hand, it is easy to draw up a special theory in favor of any system of boiler, and so many writers of apparently scientific treatises have misused this facility that it is considered childish to follow their example.

Those theories that lead to the conclusion that Belleville boilers cannot possibly work well need no discussion; if, despite theories and theorists, these boilers insure safe service on more than two hundred ships of all dimensions and in at least a thousand workshops, these theories and theorists are wrong. Industrial progress has always become evident before theory could succeed in explaining it; on the contrary, how many are the failures when it is desired to bring into actual practice attractive conceptions based only on their harmony with the best established scientific principles.

## Chapter I.

### INSTANTANEOUS STEAMING BOILERS.

#### 1850-1859.

As soon as steam began to be used as a motive power, a few years before the middle of the last century, it was known that progress in steam engineering would be checked until high-pressure steam could be used and safely produced.

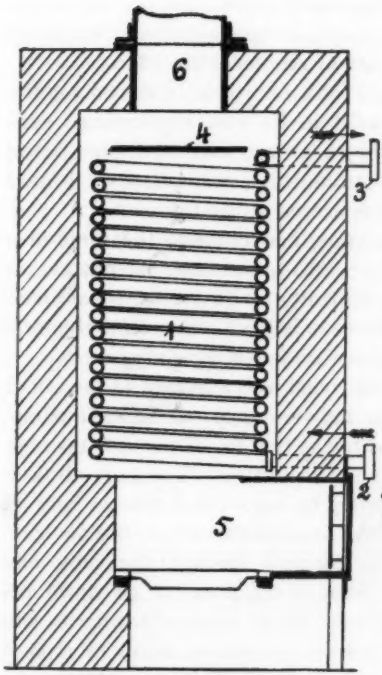
Therefore, numerous attempts were made at that time toward that result. But the task was arduous; not only was a new apparatus to be created, but the metallurgical industry was to be brought to provide for new requirements. The latter was, for a long time, an insuperable obstacle.

While, from the beginning, innovators were innumerable, their ranks soon thinned in the face of ever recurring difficulties, and now the names of Perkins, Testud de Beauregard, Wethered, Evard, Clavière, Boutigny, Cely-Cazolat, scarcely testify to their accomplished endeavors nor to the numerous inventors who were tempted by the greatness of the enterprise.

Only one among them, Mr. Julien Belleville, was allowed to see his efforts crowned with success; he alone, perhaps, had the necessary tenaciousness and strength of mind to persist against the failures unavoidable in such a thoroughly novel undertaking. It was not, indeed, until after working eagerly for twenty-five years that he could consider the problem set before him entirely solved.

It was impossible, sixty years ago, to think of merely strengthening the boilers then in use to enable them to produce high-pressure steam; manufacturing processes were inadequate; the frequence and gravity of the mishaps that took place, even with the low pressures then employed, led to the fear that the worst calamities would result if such means were resorted to.

Seeking safety above all else, Belleville understood that new requirements must be met by new apparatus, and, starting from the principle that the consequences of an explosion are the more serious when the volume of steam and of water in a boiler is great, he created a boiler in which the steam volume was insig-



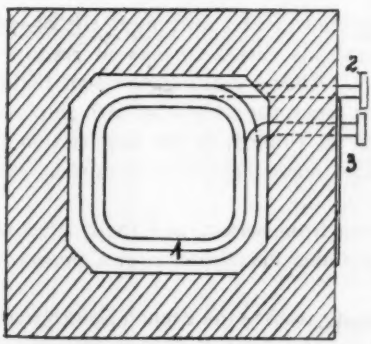




**Fig. 1.**

1. Steaming coil; iron tubes, 40 to 50 mm. internal diameter (1½ to 2 inches).
2. Feed-water inlet.
3. Steam delivery.
4. Baffle plate on top of coil.
5. Furnace.
6. Uptake.

nificant and the mass of boiling water practically nil. Such was the first Belleville boiler, so-called "instantaneous steaming boiler," for which he took a patent August 28th, 1850.

That boiler, the very simple form of which is shown on the previous page (Fig. 1), as used in its first applications, consisted merely of a coil, heated by a furnace lined with fire bricks; the water, admitted at the bottom, was instantaneously heated and the steam produced was delivered at the top.

That idea, apparently so simple, had come to the mind of a great many inventors, even previous to the 1850 patent; but all had failed on account of the difficulty of generating steam continuously under such conditions. Belleville overcame this first obstacle by means of his *pressure and feed regulating valve.*

That essential feature, a real relief valve loaded to the boiler pressure, was placed on the delivery pipe of the feed pump, which was directly connected to the bottom of the coil through a small port, without any non-return valve. The port allowed the water delivered by the pump to enter the boiler so long as the pressure did not exceed the load on the valve; but as soon as it was exceeded the water escaped through the valve and ceased feeding the boiler. Should the pressure go down because some steam was delivered, water again entered the coil and instantaneously formed a fresh volume of steam to replace what had been used. This intermittent action took place quite regularly.

The first trial boilers were built of cast-iron pipes, the shape and thickness of which were vainly varied to prevent ruptures caused by unequal expansion. After a year's experiment Belleville was led to use iron gas pipes, the only kind of iron pipes that could then be procured in France, as the importation of English lap-welded iron tubes made especially for boilers was then prohibited.

But these gas tubes were far from perfect, and their defective welding caused the inventor numerous failures over a period of five years.

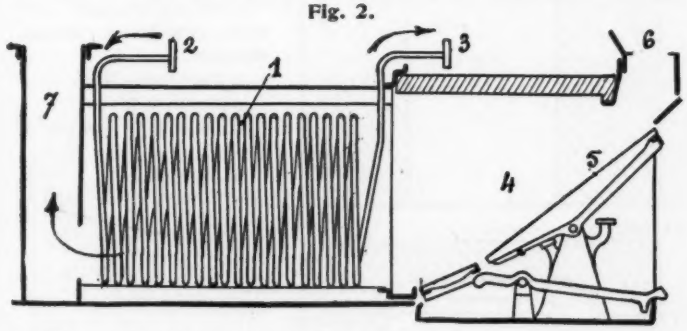
Notwithstanding this difficulty, in 1854 the French Navy agreed to try the new boiler on the dispatch boat *Biche*, but the experi-

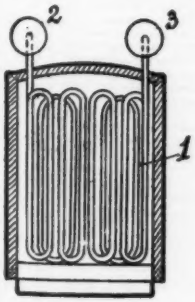
ment was without success. The tubes, stuck rather than welded, opened without exploding, under the mere effect of a few successive contractions and expansions, giving way more or less rapidly according to the adherence of tube edges. In one run from Cherbourg to Brest three boilers out of four became thus unserviceable.

A decree of 1856 having cancelled the prohibition on English tubes, such mishaps ended, and in that year it was possible to fit new boilers in the same dispatch vessel with some appearance of success, and also in the ship *Seine et Rhone*, of the "Compagnie Générale Maritime." The sketch (Fig. 2) shows the general outline of the boilers fitted in the latter ship. In these new experiments the original coil was modified in shape and in position.

The vertical coil was replaced by two concentric coils having a horizontal axis and placed on the same level with the furnace.

Fig. 2.




1. Steaming coil; iron tubes, 70 to 80 mm. internal diameter (2¾ to 3¼ inches).
2. Feed-water inlet.
3. Steam delivery.
4. Furnace, with cleaning device at the back.
5. Grate bars.
6. Coal-feeding box.
7. Uptake.

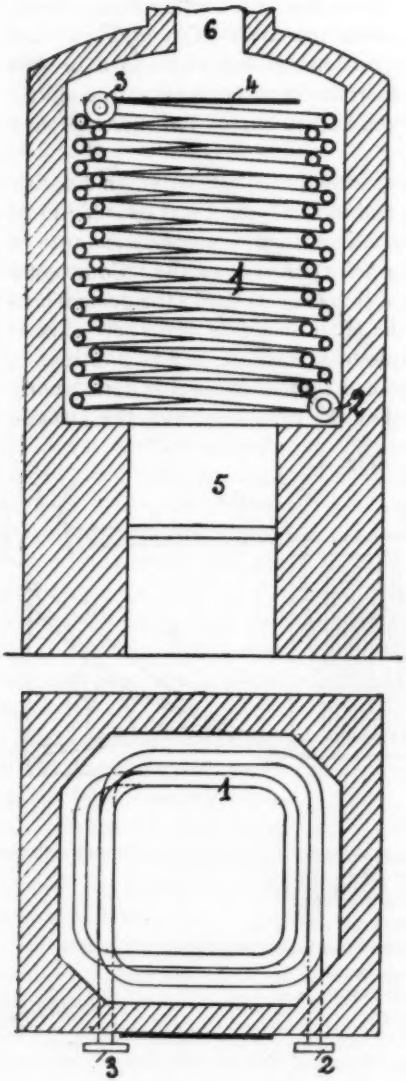



**Fig. 3.**

1. Double steaming coil; tubes 40 to 50 mm. internal diameter.
2. Feed-water inlet.
3. Steam delivery.
4. Baffle plate on top of coil.
5. Furnace.
6. Uptake.

Moreover, the feed entered the boiler at the after end of the internal coil, in which water circulated, coming nearer to the furnace as it became warmer. The steam formed circulated in the external coil, from near the furnace towards the back end, and its pressure acted on the feed-pump delivery to equalize the load on the regulating valve. By that arrangement a sudden formation of steam, which formerly often took place, was avoided.

Under these various shapes, the principle remaining exactly the same, several installations were made on land, and even on locomotive No. 51 of the Eastern Railway Co., of France. The latter ran regularly during a month between Epernay, Chalons and Bar-le-Duc.

The variations of shape can be appreciated from the adjoining sketches, Fig. 3, which represent installations in the establishments of Philippe Vian, of Paris, and Motte Bossut, of Roubaix, and Fig. 4, showing a boiler fitted at the works of the "Société Crosnier," in Paris.

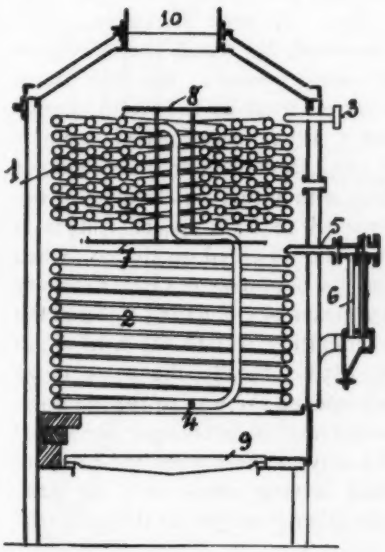



**Fig. 4.**

1. Concentric coils used as feed-water heaters.
2. Steaming coil.
3. Feed inlet to No. 1 coil.
4. Feed inlet from coil No. 1 to coil No. 2.
5. Steam delivery.
6. Temperature governor.
7. Baffle on top of steaming coil.
8. Baffle on top of feed heater.
9. Furnace.
10. Uptake.

It seemed that henceforth a few minor alterations, rendered necessary, for instance, by the difficulty of regulating the fire intensity according to steam production, would enable that type to answer naval and industrial requirements. Unfortunately, the rapid deterioration of tubes, frequently heated red and suddenly cooled by feed water, was soon found to be an insuperable difficulty. The defect was inherent to the system and serious enough to condemn it everywhere. Indeed, the boilers under trial were thrown aside, and Belleville was compelled to acknowledge his failure in the attempt to produce instantaneous vaporization in a practical manner.

But before admitting that failure he exerted every effort to avoid it, and exhibited his great skill in the remedies proposed. Combustion with the aid of steam blown under the grate, so much used subsequently, is employed for the first time (patent dated August 28, 1850); the shape of the tubes is varied in each new installation, of which the principal arrangements were covered by additions to the original patent, November 30, 1851, April 5, 1853, August 3, 1853. A draft regulator, called "temperature governor," is invented, by which the activity of combustion is regulated by steam pressure; the first steam separator, in which the water carried away by the steam is separated from it, appears August 3, 1853. Superheated steam is proposed April 14, and July 8, 1854, though engines were not yet fit to use it; continuous stoking, with automatic cleaning of fire bars, is practically realized June 18, 1856; a special feature is adopted, that allows cold air to be admitted on the coil when engines are stopped, to prevent its becoming red hot, February 23, 1858. Superheated air, by means of circulating it round the smoke conduits previous to admitting it into the ash pit, is already applied February 28, 1858. Finally, the principle of multiple steaming tubes, which opened the way to the innumerable multitubular boilers invented later on, is brought into actual practice August 9, 1858, at the very moment when the failure of instantaneous vaporisation was leaving unsolved a problem, the solution of which was most eagerly sought by the industrial

world, namely to find a boiler capable of quickly, safely, economically and continuously producing high-pressure steam.

In the face of all these consecutive creations the question naturally arises: Which is more admirable, the inventive genius thus revealed, or the prescience that allowed the inventor to foresee the requirements which, later on, the new-born industry of steam boilers should have to meet? Indeed, in all these daring innovations and departures we must see the slowly developing germ of the great numbers of successful adaptations which had their prosperity under other names. However, they were not all abandoned by the inventor, and, after fifty years, we still find the separator, the draft regulator, and the multiple independent steam circuits, which followed the Belleville boiler in all its transformations and were modified to fit new arrangements.

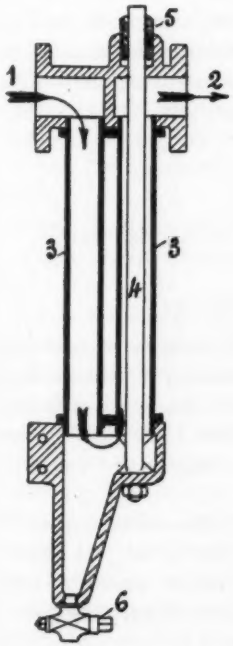



**Fig. 5.**

1. Steam inlet.
2. Steam delivery.
3. Iron tubes.
4. Metallic rod secured at its lower end and free to expand upwards.
5. Stuffing box.
6. Blow-out cock.

At that time the separator consisted merely in a cast-iron tank divided in two compartments by a partition hanging from the top and not reaching the bottom; steam was admitted at the top of one compartment, went round the partition and was delivered on the opposite side. As in all similar apparatus, even now, the inertia of the water was used to separate it from the steam.

The temperature governor consisted in a cylinder immersed in steam, usually fitted at the top of the separator, and filled with a liquid-producing high-tension vapor under the action of temperature; in that cylinder worked a piston, the rod of which governed, through chains and pulleys, the draft register.

Later on the cylinder was replaced by a rod fixed at one end, as shown on the sketch, Fig. 5, and the expansion of which acted on the register.

As to multiple steaming circuits, they will be seen in use from the first type which superseded the instaneous boiler, and the description of the various subsequent types will especially refer to the modifications of the original arrangement.

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## Chapter II.

### BOILER WITH MULTIPLE ELEMENTS AND LIMITED CIRCULATION.

**1859-1875.**

#### 1. Small-tube Boilers; 1859-1862.

We will term this type "the boiler with multiple elements and limited circulation," although Belleville named it "the multiple circulation boiler," in order to adopt a well known classification which ranks in that category boilers where "the water has no other movement than that necessary to replace the vaporised water."—[L. E. Bertin, Marine Boilers.]

There is thus established an essential discrimination, which seems to have escaped the attention of the writer just quoted, between that transitory type and the present Belleville type, which ought to be classified, as demonstrated later, among boilers having an accelerated circulation.

In 1859, and even a long time afterwards, the advantages of water circulation in boilers were ignored; they were only recognized after the result was obtained without having been sought. The tubular or tank boilers which it was then desired to replace by others had such a limited circulation that public attention had never been drawn to the usefulness of that phenomenon which has been ever since so much used for advertising purposes.

When Belleville created that type he at once understood what its future would be, and explained the advantages of it with remarkable clearness in the memorandum annexed to his application for a patent, on the 6th of May, 1859. "This patent," he said, "involves a capital improvement to the inexplosible boiler, patented August 28th, 1850, which renders the Belleville boiler thoroughly practical for all purposes.

"1st. New arrangement of the whole system for bending tubes and connecting them together.

"2d. Application of the principle of equilibrium in communicating vessels to the various parts or 'circulations' of a boiler and between any number of boilers working together.

"3d. Employment of a new apparatus called 'separating water level.'

"4th. Injection of feed water into the steam.

"5th. Surfaces containing water to be alone in contact with fire.

"6th. Steaming elements very easily dismounted, replaced and internally cleaned."

This very simple exposition shows the complete change in the course followed for the preceding ten years. A new arrangement was born, in which the origin of the present boiler could already be discovered—still a very imperfect conception, but one from which all the causes of the failure of instantaneous boilers were removed. The annexed sketch showing the installation erected in the Chauvine works, in Paris, gives an idea of the general outline of the new boiler. (Fig. 6, next page.)

The spiral coil, vertical or horizontal, is abandoned and replaced by a vertical bundle of independent steaming tubes, curved

in different ways, already approaching the U-form, with their straight portions shyly arranged above the furnace which were soon to be extended until they formed the whole of the tubular bundle. Each of these tubes is connected at the bottom with a water collector, and at the top with a steam collector called "dividing collector." That combination, absolutely unknown at the time, of several steaming tubes or coils in one single boiler, caused the new type to be termed "an inexplosible boiler having multiple circulation." The new boiler was quite favorably accepted by the French industries, and the Navy, guided by its highest technical authority, Mr. Dupuy de Lôme, adopted it in 1860 for the dispatch vessel *Argus* and later on for the transport ship *Vienne*.

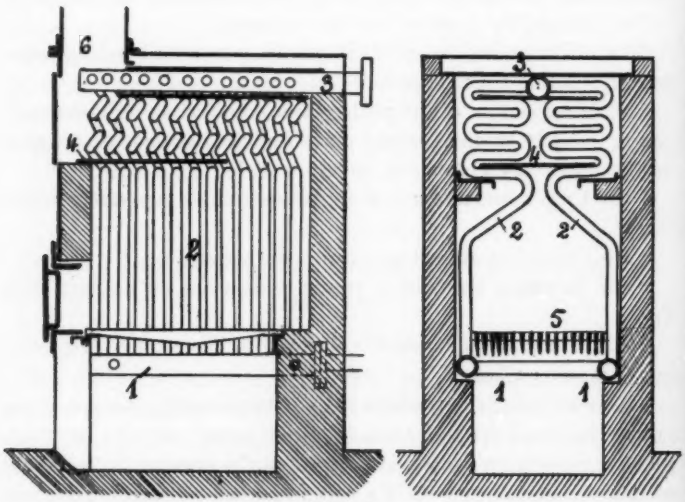


Fig. 6.

1. Feed collectors.
2. Steaming tubes.
3. Steam collector.
4. Baffle plates.
5. Furnace.
6. Uptake.

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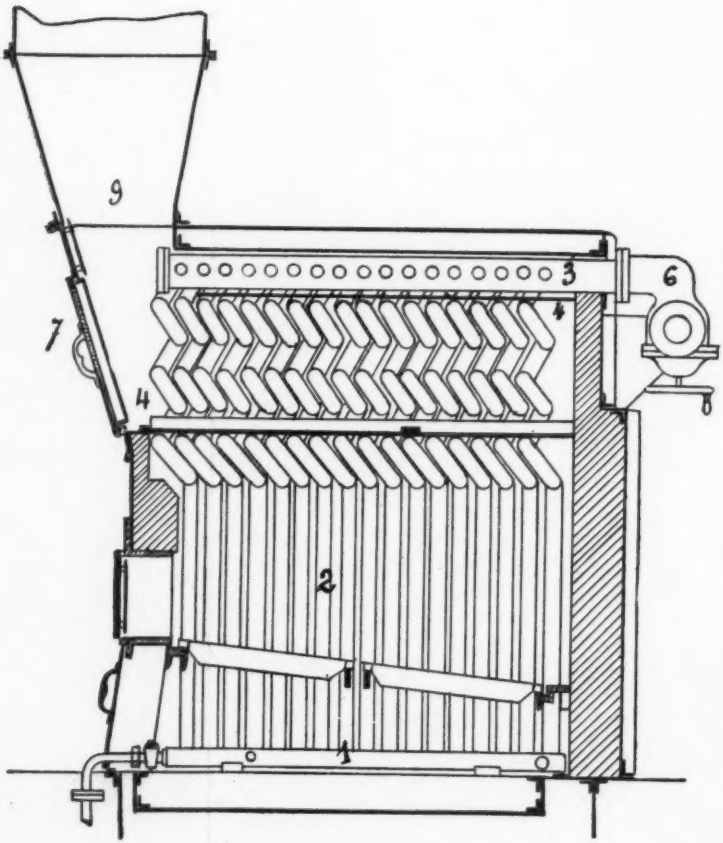


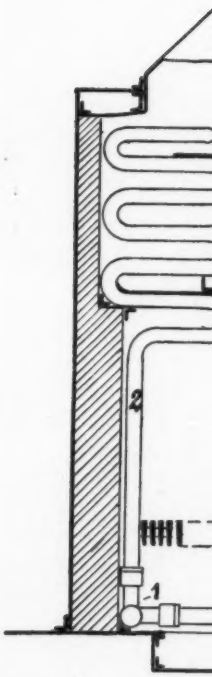
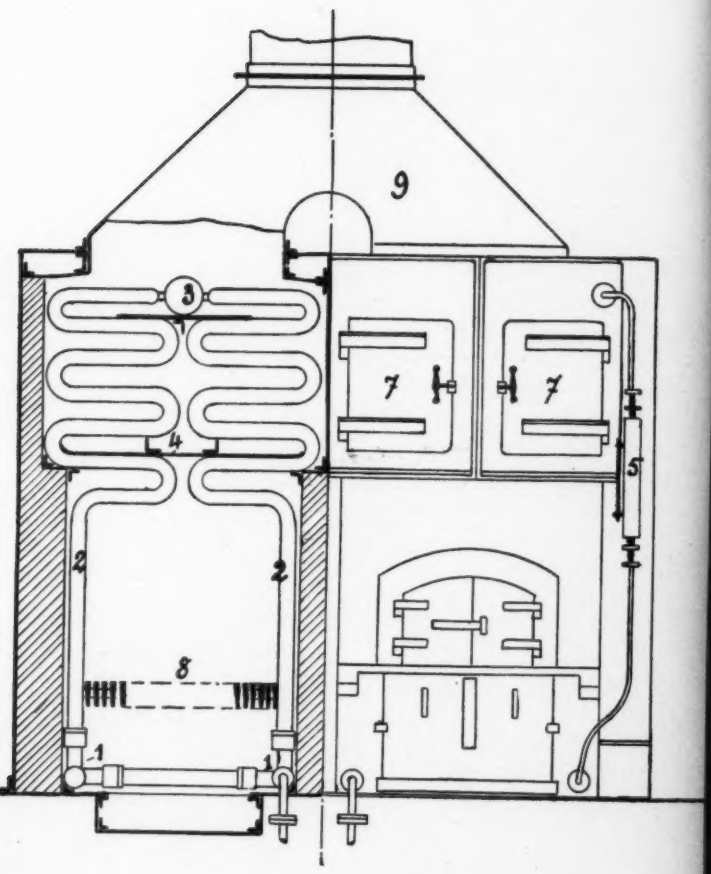




**Plate 1.**

1. Feed collectors.
2. Steaming tubes.
3. Steam collectors.
4. Baffles in steaming-tubes bundle.
5. Water level and float box.




6. Steam valve.
7. Front cleaning doors.
8. Furnace.
9. Uptake.

In this affair Depuy de Lôme was not influenced by the fear of seeming to stultify himself; he himself had proposed to the Minister, in 1857, to discontinue the trials that were being made on board the *Biche* with the first Belleville boiler, yet in 1860 he advertised the use of the newly-designed type, and the praise he bestowed on it a few years later was summarized in the following terms: "I regret one thing, which is that the compulsory use of sea water, which so rapidly scales our big boilers, still delays the final employment of these water-tube boilers in the Navy, but soon, perhaps, surface condensers, free of the defects of those that have been already tried, will permit of Belleville boilers being fed with steam condensed after having done its work in the cylinders, and then a very important advance will have been made."—("Moniteur," of May 28th, 1866).

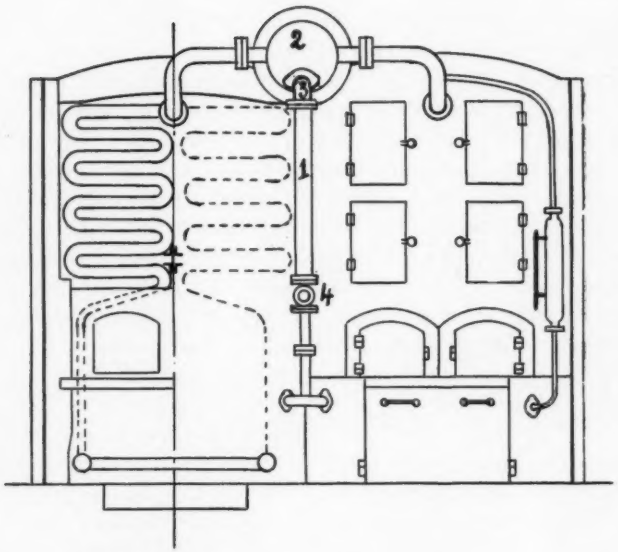
An examination of the annexed sketch (Plate I), shows the striking analogy which exists between that boiler and the Du Temple boiler, wherefrom the collection of so-called "small-tube boilers" originated.

Immediately after creating this new type, Belleville took advantage of the observations he had previously made on the formation of scale on heating surfaces, by adopting the injection of feed water amidst the steam, which thenceforth became an essential feature of his boilers. He had noticed that the deposits, formed by the precipitation of the salts contained in water, accumulated at a certain distance from the feed nozzle, and had concluded therefrom that the salts were separated from the feed water as soon as the latter reached a certain temperature. Therefore, by injecting the feed water into the steam, he raised its temperature and consequently precipitated the salts far from the heating surfaces, which were thus freed from scale.

This idea, demonstrated to be right many years later by the works of some scientists on the solubility of salts, was not then accepted without reserve, but, since that time, it has been universally convincing, and now all water-tube boilers, without exception, have their feed water introduced into the steam.

Again, in this new boiler appears the separator created during Belleville's researches on instantaneous vaporisation; it is not

Fig. 7.




1. Feed regulator.
2. Steam chest.
3. Connection between 1 and 2.
4. Connection between feed regulator and water collector.

much modified at first; its volume is only greater, which renders it more effective, and it is usually made a part of the water-level tank, which is a simplification.

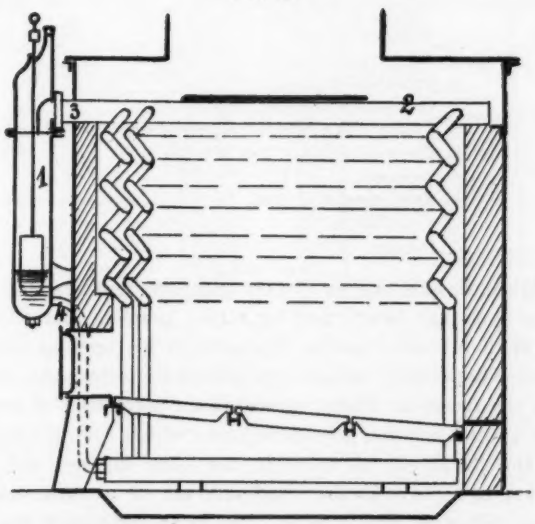
The water-level tank, not used in former types, was becoming necessary, since there was an actual volume of water in this boiler; but it seems to be reluctantly employed, and, as if to legitimise its presence, it is made to fulfil other functions; it serves as a separator, as above stated; sometimes it gets the feed water at its upper end, and also the steam inlet from the upper collector, and it bears the steam delivery. But it soon begins to fulfil its real duty and becomes an integral part of the boiler when it is finally fitted with a float, the rod of which acts on the feed cock.

It then forms, still in a rudimental manner, what later becomes the automatic feed regulator, the perfect working of which now contributes to the success of the Belleville boiler.

While simplicity was obtained by the combination of so many different features in the float box, serious inconveniences were experienced. The working of the float, for instance, was disturbed by water and steam eddies, and the indications of the water-level glass were inaccurate. Therefore, it became necessary to make the water column with its floats independent, so that, during several years, continuous alterations resulted in the grouping of accessory parts. The external appearance of the boiler was thus modified, although the original principles were retained, as shown in Figs. 7 and 8.

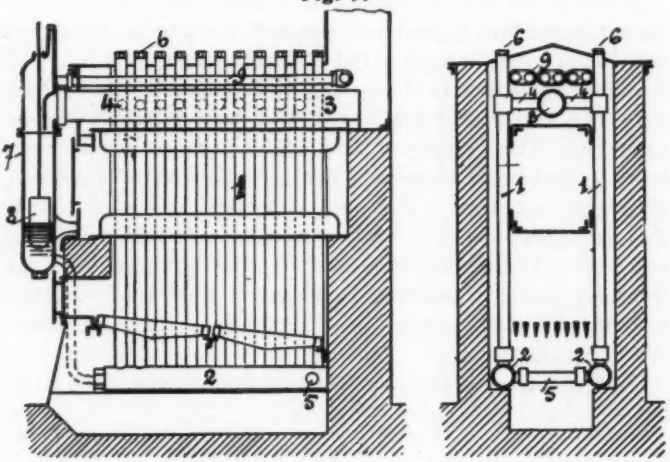
Our present experience in water-tube boilers enables us to see

Fig. 8.




1. Feed regulator.
2. Steam collector.
3. Connection between 1 and 2.
4. Connection between feed regulator and water collector.

Fig. 9.



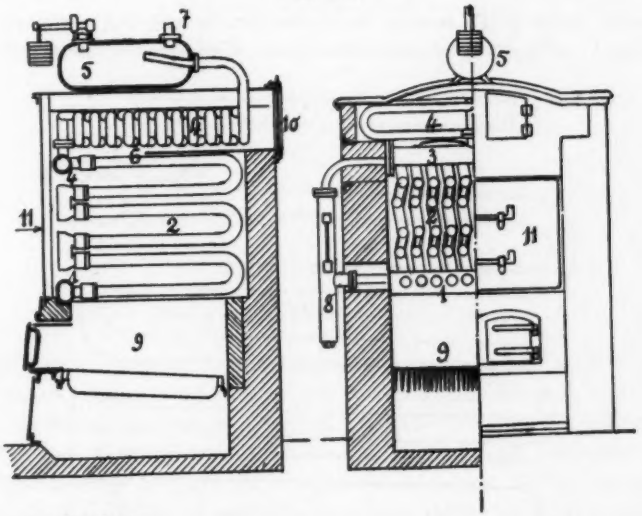

1. Steaming tubes.
2. Feed collectors.
3. Steam collector.
4. Connection between 1 and 3.
5. Connection between feed collectors.
6. Cleaning plugs on top of tubes.
7. Separator.
8. Feed-regulating float.
9. Superheater.
10. Uptake.

at a glance, despite the important improvements carried out in the new type and sanctioned by actual practice, that the chief defect of that boiler was the impossibility of cleaning the inside of tubes, which easily became scaled and were burned. Feeding amidst the steam no doubt prevented the formation of scale to a certain extent, but the muddy deposits which took place endangered the durability of tubes in the same manner, and it was necessary to remove them. Belleville set to work to overcome that new difficulty, and in June, 1860, in an addition to his patent of May, 1859, superseded the corrugated steaming tubes with a new design, in which they were vertical and straight (Fig. 9). At the top a cleaning plug was fitted, allowing a "percussion or rotating tool" to be introduced.

While this arrangement permitted easy cleaning, it was not favorable to efficiency, and therefore had to be abandoned. Thus, until October, 1861, some minor details excepted, the "*Argus*" type was preserved.

On that date an addition to the main patent brought the boiler to a new stage which contributed greatly to its final success and made it quite a new type as far as its general constitution is concerned, the original principles still being adhered to.

Fig. 10.

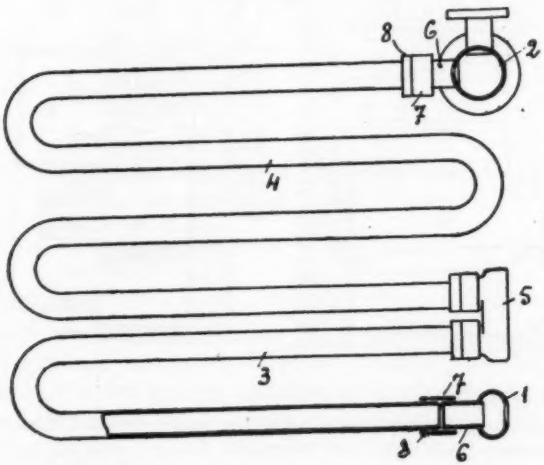



1. Feed collector.
2. Steaming elements, consisting of horizontal tubes bent at back end and connected by junction boxes at the front.
3. Steam collector.
4. Steam drying tubes.
5. Steam chest.
6. Baffle plates.
7. Steam valve.
8. Float box and water level.
9. Furnace.
10. Draft register.
11. Front cleaning doors.

### 2. Models with horizontal, bent, U Tubes, 1862–1868.

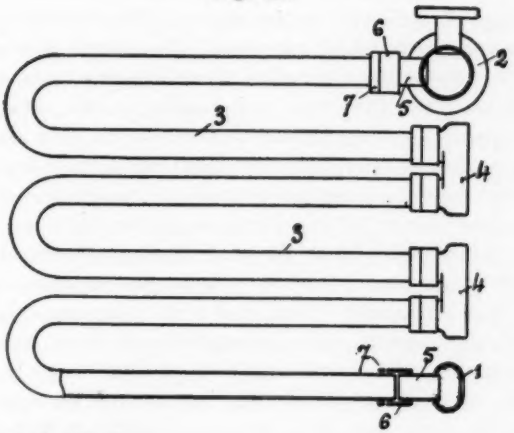
In this new arrangement, Fig. 10, page 403, the general outline, which seemed to lead to what, later on, was the Du Temple boiler, is radically thrown aside by suppressing one of the inferior collectors; besides, the vertical part of the steaming tubes, which was useful only on account of the collector being far below the grate, disappears, and the corrugations start from the collector raised above the furnace door, which situation it has kept ever since. But progress is marked especially in the shape of the corrugations. They consist of a series of three tubes, bent to the shape of U's, having their branches in a vertical plane and placed horizontally above each other. The lower branch of the

Fig. 11.




1. Feed collector.
2. Steam collector.
3. Tube bent at the back.
4. Tube bent at the back and front.
5. Front junction box of tubes 3 and 4.
6. Short pieces of tube screwed on water and steam collectors.
7. Connecting screwed sleeves.
8. Safety screwed rings, to secure a tight joint.

Fig. 12.




1. Feed collector.
2. Steam collector.
3. Tubes bent at the back.
4. Front junction boxes.
5. Short piece of tube screwed on water and steam collectors.
6. Connecting sleeve.
7. Safety screwed ring, to insure tightness of joint.

first U is connected to the inferior collector. The uppermost branch of the last is connected to the upper collector, and intermediate branches are connected together, each to the adjacent one, by a malleable cast-iron box, which has kept the name of "connecting or junction box," and in which the tubes are screwed. In way of each tube is a hole, closed by a plug, easily removable. Each series forms what has been later on called an "element," and what Belleville had originally called a "feuillet" (leaf), as he had originally termed "spines" the water and steam collectors, which then were the "lower spine" or the "upper spine." The boiler consisted of a greater or lesser number of elements, according to the quantity of steam to be delivered.

The first models had only connecting boxes between the upper branch of the lowest U and the lower branch of the second; later on another box was added, but, since 1863, all tube

ends were connected by boxes. Fig. 11 shows the first arrangement, Fig. 12 the latter, pages 404–5. The screwed junction of tubes and boxes, which now seems very simple, was a serious difficulty forty years ago, when threading machines were far from the perfection they have now reached. This is the reason why Belleville used connecting boxes only on land where feed water was often impure, and kept, until 1865, the "*Argus*" type for marine boilers, on account of surface condensers.

It must be recognized, nevertheless, that however imperfect a screwed joint might be at the time, it was still better than the expanded joints then in use in tubular boilers, (tube ends expanded with a mandrel). Since that time roller expanders have brought about a great improvement, but experience has proved that a steaming tube joint cannot be kept tight in the fire unless screwed. It is, therefore, in order to secure the tightness of tubes and to allow them to be easily removed, that Belleville has adhered to screwed joints; moreover, he brought them to a degree of perfection such that many still consider it scarcely obtainable, though it is the mere result of using proper tools of the utmost simplicity. This point is insisted upon because criticism is often heard about these screwed joints, under the pretense that, after a certain time, they can no longer be unscrewed. The only thing claimed for these joints is tightness, and this is enough. They have always been tight in boilers made in Belleville works. Easy dismounting and repairing especially results, in recent types, from the fact that the complete elements are portable.

During that period, from 1862 to 1865, some improvements were made to the grouping of accessory parts, the functions of which became more definite, so that they finally became independent. After some hesitations, in order to avoid sudden outflows of steam liable to cause priming, the steam delivery section was reduced to the proper size by means of a pipe pierced with small holes and fitted over the whole length of the steam collector.

But progress is especially noticeable in the execution of the work. The care taken in using perfect materials; the improved

processes of cutting threads; the new arrangements adopted for joints submitted to high pressures, all concurred in increasing the value of the new boiler, and since that time the Belleville boiler has won the reputation, which it now maintains, of being constructed in a faultless manner.

After reaching this point the inventor had reason to be proud of his work, and on November 22d, 1865, when taking a new patent where the new improved boiler was described, he could, with legitimate pride, express himself as follows: "After fifteen years continuous researches and experiments, I have arrived to the complete practical realization of the inexplosible boiler that has been so long sought for * * * ." "It is mainly to a minute study of details, often apparently insignificant, that I am indebted for my success * * * ."

It can now be rightly said that this boiler was still far from satisfactory; but we must recognize, from the great number of such boilers used at that time, that they rendered very good services. Some of these boilers were still in use in 1898, since the Belleville works were then called upon to repair a boiler having U-shaped tubes, which means 33 years' existence.

Among the installations during that period (1862–1868) are those at Plon's printing establishment, Paris; at the "Petit Journal," where Belleville boilers have been used ever since; at the Weapon Works, St. Etienne; at Henry & Son's, Savonnières, near Bar-le-Duc, where a boiler supplied in 1866 is still at work, their successor, Souplet, having ordered from the Belleville works, May 18th, 1899, a spare U-tube, thus showing that this boiler delivered more than thirty years ago is still in service. To sum up, during these six years more than 300 boilers were supplied to various industries.

Aside from some small defects, such, for example, as the system of junction of the elements with the collectors, which caused repairs to be somewhat difficult, a serious defect still existed, and was not thought of in that initiatory period, viz: the deficient circulation, which rendered it necessary to watch the water level with the utmost care to prevent it rising above a limit at which priming could not be avoided.

For that reason all Belleville's endeavors were concentrated upon the design of an apparatus to govern the amount of feed water automatically.

On September 20th, 1866, and September 4th, 1868, additions to the 1865 patent give evidence to the steps taken towards that end, which finally resulted in the automatic feed regulator, represented on Fig. 13.

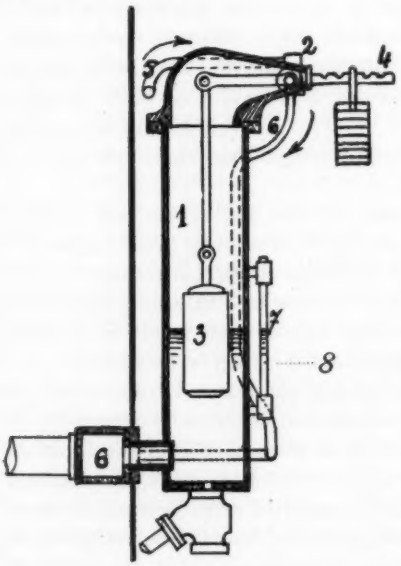



**Fig. 13.**

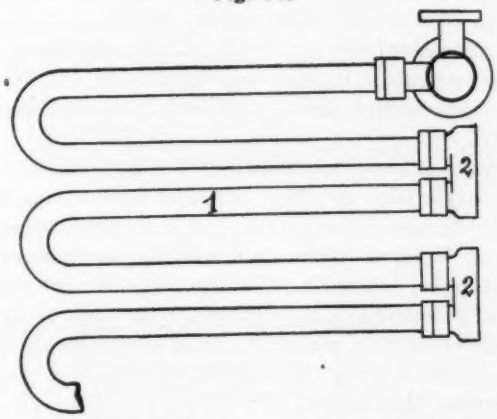
1. Float box.
2. Automatic feed cock.
3. Float acting on feed cock.
4. Graduated lever with balance weight.
5. Feed inlet to cock.
6. Feed delivery to feed collector.
7. Feed collector.
8. Water-gauge glass.

The U-shaped tubes, successfully employed from 1862 to 1868, although having a marked advantage over the former coils, could only be cleaned with great difficulty in the curved part, which might even be pierced by cleaning tools roughly handled. By a fortunate alteration, the shape of tubes was then modified by omitting the curved part and replacing it by a junction box similar to that already connecting the ends of the U-shaped tubes. The principle of the boiler remained unaltered, but the shape of the bundle of steaming tubes was entirely remodeled, and distinguishes the new type, which was employed until 1872.

### 3. Model having Straight-Tube Elements, 1868-1872.

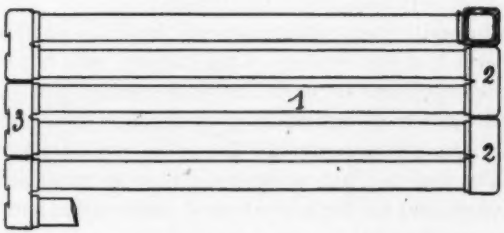
In this new type the elements consist of straight tubes connected at both ends by junction boxes. The advantage of this arrangement is that it not only facilitates cleaning the whole length of tubes, but also brings the tubes closer to each other in a vertical direction, and consequently places a greater heating surface within a given space. Figs. 14 and 15 show the difference in the appearance of these arrangements.

**Fig. 14.**




1. Tubes bent at back. 2. Front junction boxes.

**Fig. 15.**




1. Straight tubes.
2. Front junction boxes.
3. Back junction boxes.

The new model, represented on Plate 2, remained unaltered, with the exception of a few minor improvements, for the four years during which it was employed. It seems at that time to have fulfilled all the conditions required in a water-tube boiler, and the French Navy which, since the *Biche* trials, in 1855, had watched with interest all improvements in the Belleville boiler and had continuously used it in small craft, launches, and in the dockyards, considered that the time had come for a renewed trial on larger vessels. In order to compare the results expected from the new type with those given by the old one, it was installed in 1867 on the *Argus*, which, since 1860, had been running with boilers of the 1850 type. The comparison revealed such improvements in the new type that, as early as 1869, it was placed in the dispatch vessel *Actif* and in the Imperial yacht *Hirondelle*.

The results obtained on both these vessels show the advance since the *Argus* trials in 1860. The trial trips of the *Actif* took place in three runs—March 12th, 15th and 16th, 1869—without any adverse incident. After each trial the committee declared itself thoroughly satisfied: "Consequently the committee has unanimously declared that the clauses of the contract are amply fulfilled and that it is proper to accept the Belleville boilers as fitted on board the *Actif*."—(Official account of the meeting of the committee, March 15th, 1869.)

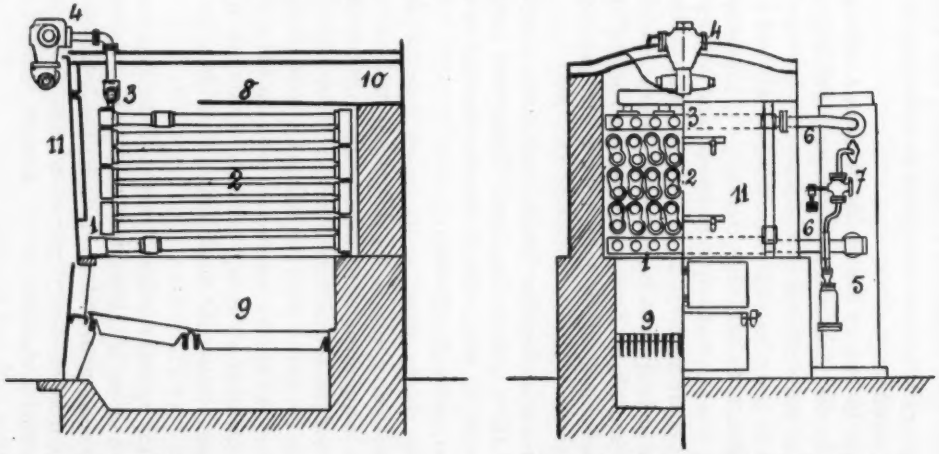
Extracts from the report on the construction and sea trials of the Imperial yacht *Hirondelle* with supply information concerning the conditions under which the boilers of that vessel were fitted and upon the results of their trials.

"The Imperial yacht *Hirondelle* was built for the Emperor's private service, at the expense of his Majesty, who himself determined the conditions to be fulfilled and selected the builders to whom he desired to entrust the construction of hull and machinery. The Emperor desired the yacht not only to be fit for his use and pleasure, but at the same time to serve as an interesting experiment for the sake of naval construction and progress in marine engineering.

"The hull was built at Hâvre by Mr. A. Normand, after his own designs * * * .

**Plate 2.**

Model with simple elements, of straight tubes.—1868–1872.




1. Feed collector.
2. Steaming elements, consisting of horizontal tubes forming a coil.
3. Steam collector.
4. Steam separator, bearing steam and safety valves.
5. Float box and water level.
6. Connection from steam and feed collectors to float box.
7. Automatic feed regulating cock.
8. Baffle plates on top of tubes.
9. Furnace.
10. Uptake.
11. Front cleaning doors.

"The boilers are of the Belleville water-tube system; they consist of twelve boilers constructed on the type of the *Argus* boilers with some slight alterations in feed boxes, and the addition of fusible plugs placed on the tubes, as a warning in case of failure in the supply of feed water.

"High-pressure boilers of the Belleville system offer a distinct advantage as they are capable of carrying very high pressures with perfect safety against explosions; they are very low, which permits their being located entirely below the deck; very light and easily installed, since they weigh only 115 tons, water included, *i. e.*, .255 ton per nominal horsepower, and require only a volume of 293 cubic meters, *i. e.*, .650 cubic meter per horsepower, while the ordinary tank boilers, with steam chest, weigh .430 ton and occupy about 1.0 cubic meter per nominal horsepower. They were shipped in light parts, easily handled and quickly erected."

The first sea trials, undertaken October 21st, 1869, discovered a few defects in the working of engines. These were corrected previous to the official trials, which were carried out in three days, March 21st, 22d and 23d, 1870.

The committee clearly stated in its report that the boilers caused none of the delays due to the refitting of engines:

"In the experiments previous to March 21st it had been found that the screws had not sufficient resistance to allow the required 1,800 I.H.P. to be developed with 130 maximum revolutions, and that the feeding of the boilers was not ensured, on account of a considerable quantity of air being delivered by the air pumps into the fresh-water tanks and remaining mixed with the feed water.

"When mentioning these delays, which will be forgotten on account of final success, it is important to state that during the whole time since the month of August the Belleville boilers have never given any trouble; that they met all that was expected from them, and, finally, that they always worked perfectly when the pumps supplied sufficient feed water.

"The draft is very good, raising steam is very quick. Steam

is got up after 15 minutes, and it is then possible to warm the engines ready for starting 30 minutes after lighting fires."

Finally the official trials, which, as already stated, took place on three consecutive days, gave every satisfaction, and the committee summed up their impressions as follows:

"The trial trips of the *Hirondelle* show a decided improvement in ship building under the Emperor's initiative. The success was mainly due to the use of Belleville high-pressure inexplosible boilers, at once powerful and light. Owing to these boilers, it was possible to place powerful engines with perfect safety on so small a vessel and to obtain a speed attained by very few ships up to the present day, or, indeed, by no vessel of so small dimensions, carrying sufficient coal to steam for two days."

Considering the great progress of the Belleville boilers in the thirty-three years since the above was formulated, it is fair to affirm that now, even more than at that time, they deserve the praise that was so freely bestowed upon them.

During the trials of these two vessels, *Actif* and *Hirondelle*, experiments were undertaken with a view to working the boilers with sea water. These gave satisfactory results, which were officially reported.

On the *Actif*, March 16, 1869, during one hour the boilers were exclusively fed with sea water.

"The committee disembarked after having witnessed every stage of the trial. Then they again met on board the *Actif* the next day, March 17th, at 1 o'clock. Plugs in a vertical row were removed from each boiler, and, after ascertaining that there was no trace of salt in the tubes, the boilers were finally accepted."

The official trial report of the *Hirondelle* runs as follows:

"In the course of these first experiments opportunities presented themselves of stating that Belleville boilers are well adapted, if need be, to being fed with sea water, without any other inconvenience than producing somewhat more moisture in the steam, which is perfectly dry when the boilers are fed with fresh water * * * ."

The efficacy of introducing the feed into the steam, to prevent scaling, was officially demonstrated; but the quantity of pulveru-

lent deposits from sea water, which could not be blown out entirely, on account of their intimate admixture with the water, was almost as inconvenient as scale, and it was necessary to give up continuous feeding with sea water, a problem that Belleville long tried to solve.

It is interesting to note that at this time, when the defects of the tank boilers were deeply felt (which defects many people even now feign to ignore), the advantages of water-tube boilers were unanimously recognized. Users of these water-tube boilers all pointed out that they give the maximum safety ; that pressure is more quickly raised ; that they are less heavy and cumbersome for the same power than the tubular return boilers then solely employed, and that they are economical, easily repaired, free from priming, &c.

On that subject, a pamphlet by Lieutenant Cordes, published in 1869, under the title "A Study on Belleville Inexplosible Boilers," with subtitle, "Notes and Results of Trials gathered on board of the *Actif*," may be read with profit, inasmuch as it summarizes, after actual facts, the opinions that were then beginning to be expressed in favor of the new boiler.

After a short historical review, the author describes the *Actif* boilers and the results mentioned above ; then he sums up the advantages of these boilers, as follows :

"1. *Inexplosibility.*—This word, while it must not be understood in its absolute literal sense, is still the only suitable one to express the features that give to the Belleville boiler a great superiority over all others heretofore employed * * *. Should a tube burst through some unavoidable cause, the stokehold would not be invaded by steam, the latter being carried away by the draft into the funnel * * *.

"2. *Quick Raising of Steam.*—This valuable quality allows of rapidly coming to the rescue, of being secure from surprises, of awaiting or observing an enemy without being discovered by smoke, and without wasting fuel. It also enables a ship to prepare in a moment to meet all emergencies that could endanger her.

"3. *Considerable Reduction of Weight for Given Grate and Heat-*

*ing Surfaces.*—The total weight of Belleville boilers, at a working pressure of 8 atmospheres, is about 175 kilograms (385 pounds) per nominal horsepower, corresponding to 6 square decimeters of grate surface. The total weight of usual tank boilers, working at 2½ atmospheres, is about 470 kilograms (1,034 pounds).

"4. *Considerable Reduction of Space.*—On board the *Actif*, replacing high-pressure English boilers by Belleville boilers, had the following results: Foundations were raised by .80 meter (2 feet, 8 inches), which allowed of two fresh-water tanks, each of 1,400 litres capacity (350 gallons) being placed under the stokehold floor. The coal bunkers, notwithstanding two newly-fitted ventilators, could hold six tons of coal more than previously. A superheating trunk on the deck was omitted and replaced by a deck house for the galleys, which were previously most inconveniently located on the lower deck and in the forecastle * * * .

"5. *Economy of Fuel.*—During her full-power trial, the *Actif* only burned 1.08 kilograms per 1 horsepower, while the coal consumption at the same rate of working is usually taken at 2 kilograms.—(Ledieu, 'Treatise on Marine Engines,' vol. ii, p. 587.)

"6. *Freedom from Priming in Rough Weather.*—The division of the water mass is a very good condition in rough weather * * *. The separator is another safeguard against that danger.

"7. *Easy Repairing.*—Due to the interchan geability of all the boiler parts and spare pieces, to their lightness, to the ease with which they are dismounted, and to the use of special tools.

"8. *Low Situation of Vulnerable Farts.*—B elleville boilers are 1.30 millimeters (4¼ feet) lower than marine boilers of the low type.

"9. *Large Hatches Useless.*—In the *Actif* the alteration of boiler hatches increased the width of each deck gangway by five deck planks * * *."

Although, later on, tank boilers were made more practical than those used when the *Actif* trials brought their defects to light, still the Belleville boiler, gradually improved, has kept all the advantages it then had over them.

It will be seen, moreover, that the same statements were renewed after every fresh improvement.

During the short period from 1868 to 1872 industrial installations were multiplied, and amounted to 164 boilers. The "Forges, Chantiers and Ateliers de L'Océan," The Claparède Works, the "Forges et Chantiers de la Méditerranée," bought Belleville boilers for their workshops and for boats, dredges or yachts which they were building. Navy dockyards and war arsenals adopted them, as well as various metallurgical societies.

All branches of industry then had recourse to this high-pressure boiler, practically the only one in existence. In order to satisfy so many various requirements Belleville was led to adopt different arrangements. Then, classing the different industries in three categories, he created three corresponding types, viz:

1st. A stationary type, intended to supply steam to stationary engines of all kinds, to utilize waste heat and to supply steam for various industrial purposes, such as heating, dyeing, cooking plants, &c. This type was designed for industries allowing of a permanent installation.

2d. A type for movable engines, launches, locomobiles, fire pumps, cranes, &c.

3d. A marine type.

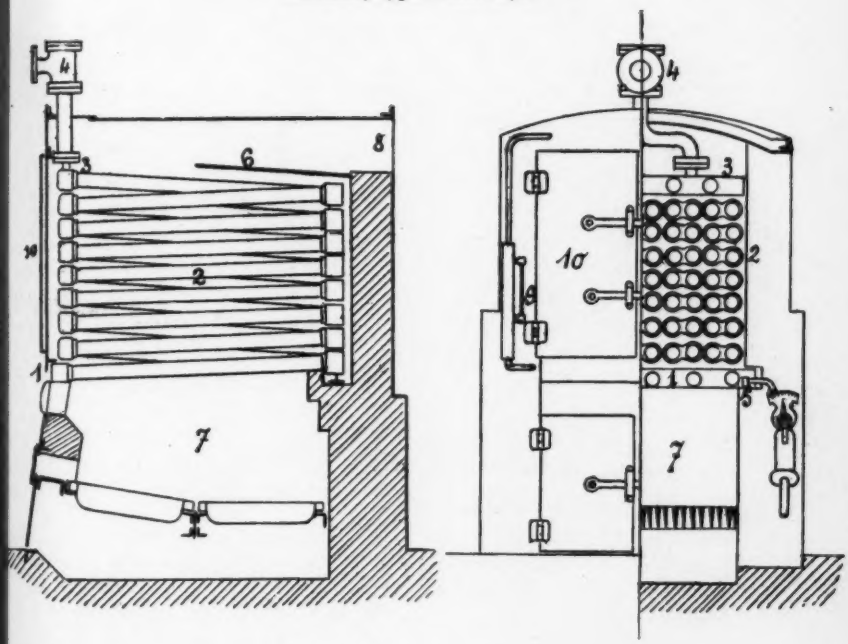
These three types were established on the same principles, and had the same assemblage of steaming tubes. They differed in their external shape, being more or less compactly arranged—in their outside casing, which was of plate work in types Nos. 2 and 3, and of brickwork in type No. 1, and in their weight. The same classification has been preserved to the present day, and there still exist the stationary, the portable and the marine type. Plates 3, 4 and 5, annexed, show the boilers of that time, with the appearance of the three different types.

The inventor had now reached the point where he might well consider his task completed. But human work is always open to improvement, and Belleville would see nothing in the tokens of interest with which his invention was welcomed by the industrial world but an encouragement to improve it further.

The series of improvements went on, and in August, 1871, a

**Plate 3.**

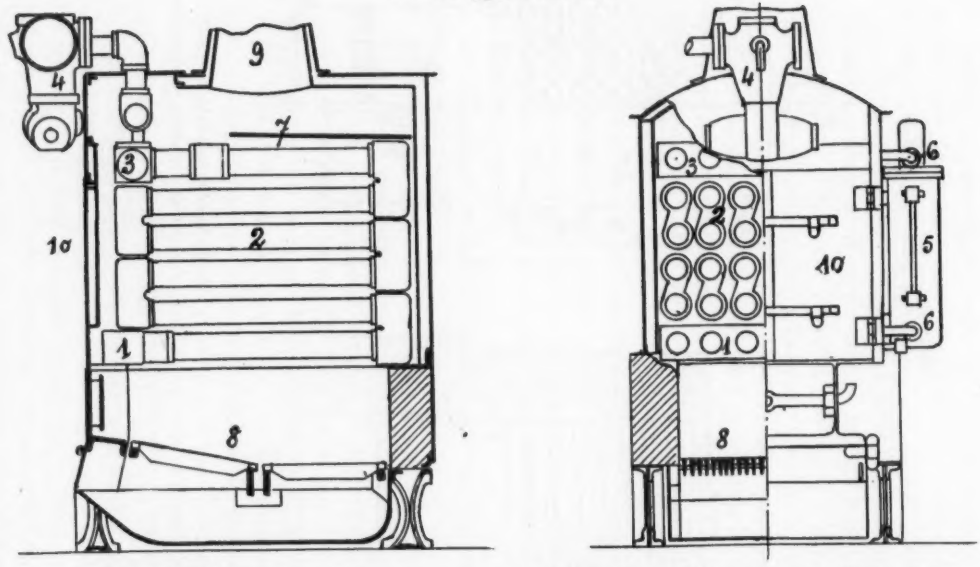
Stationary type.—1868–1872.




1. Feed collector.
2. Steaming elements, consisting of inclined tubes assembled in coils by means of junction boxes.
3. Steam collector.
4. Steam delivery **T**, bearing steam and safety valves.
5. Feed-water inlet.
6. Baffle plates on top of tubes.
7. Furnace.
8. Uptake.
9. Float box.
10. Front cleaning doors.

**Plate 4.**

Portable type.—1868–1872.




1. Feed collector.
2. Steaming elements formed of horizontal tubes connected by junction boxes.
3. Steam collector.
4. Steam separator, bearing steam and safety valves.
5. Float box.
6. Connection of steam and feed collectors to float box.
7. Baffle plate on top of tubes.
8. Furnace.
9. Uptake.
10. Front tube-cleaning doors.

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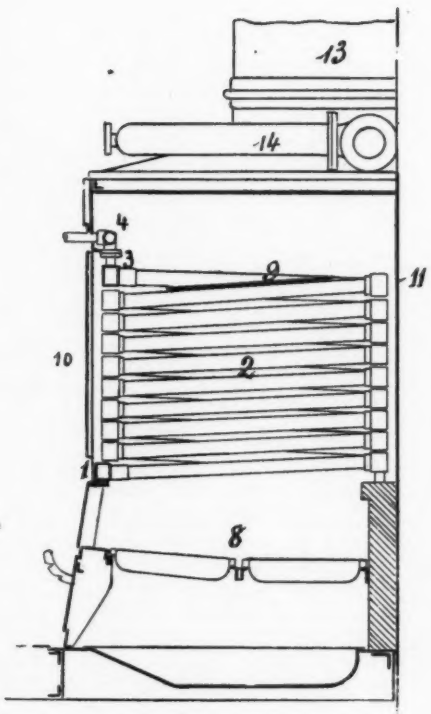


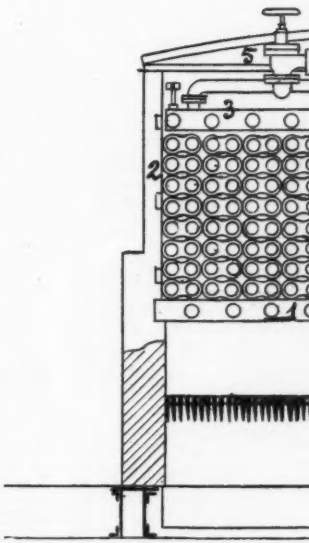
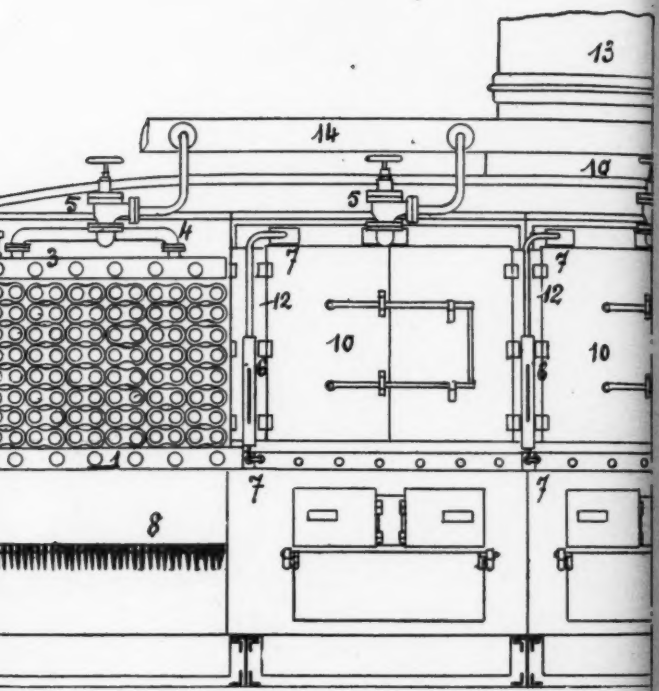




**Plate 5.**

*Actif* marine type.—1868–1872.

1. Feed collector.
2. Steaming elements consisting of inclined tubes connected in coils by means of junction boxes.
3. Steam collector.
4. Steam outlet.
5. Steam valve.
6. Float box.
7. Connection of steam and feed collectors to float box.




e 5.
pe.—1868–1872.

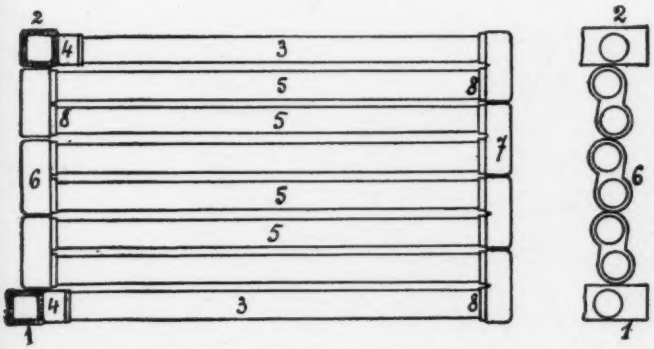
8. Furnace.
9. Baffle plate on top of tubes.
10. Front cleaning doors.
11. Transverse partition between two boilers.
12. Longitudinal partition between two boilers.
13. Uptake.
14. General steam collector.

new patent was granted, which, while still containing the double element, produced a new type of boiler as widely different from the preceding one as that in turn had differed from the 1862–68 model.

### 4. Models with Double Elements, 1872–1875.

The elements employed in the boilers built from 1868 to 1872 consisted in horizontal, straight, parallel tubes, in which steam could circulate in both directions with equal facility. Still, two obstacles prevented the downward movement of the steam: the water head, however small, due to the feed, acting on the lower collector, and the lesser density of steam compared with water, which prevented its passing downward from tube to tube through the junction box. However, especially in the lowest tube, where only a very small water head could exert itself, steam was necessarily liable to escape into the collector without circulating through the element, because the resistance of the latter might

Fig. 16.




1. Feed collector.
2. Steam collector.
3. Tubes directly connected with water and steam collectors.
4. Connecting sleeves on collectors 1 and 2.
5. Tubes without sleeves, screwed on front and back boxes.
6. Front junction boxes.
7. Back junction boxes.
8. Safety screwed rings.

be, at certain times, greater than the effect of the water head. In order to reduce this resistance it was necessary to keep a very low water level in the boiler.

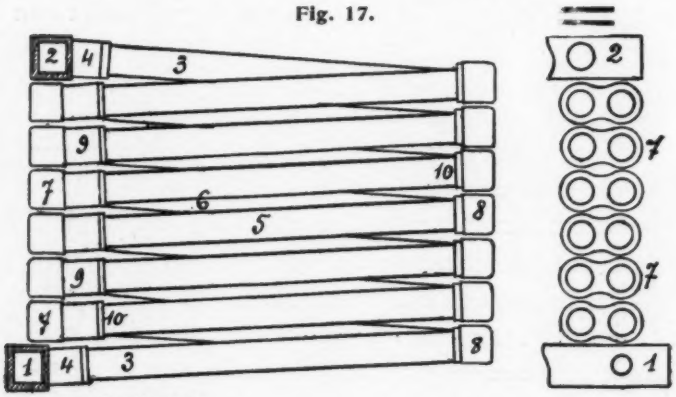
With double elements these defects were partly remedied, but they only disappeared later, when another type was devised.

The double element forms a real flat coil, with constant pitch, consisting of straight tubes connected by horizontal junction boxes, and offering a continuous slope from bottom to top. An air or steam bubble, produced at the lower part of such a coil filled with water, would be compelled, by the mere effect of its lesser density, to pass upward through it.

Fig. 17 shows how the tubes are connected and inclined, and illustrates the advantage of this arrangement for freeing the steam bubbles.

All resistance to the circulation of the steam through the tubes

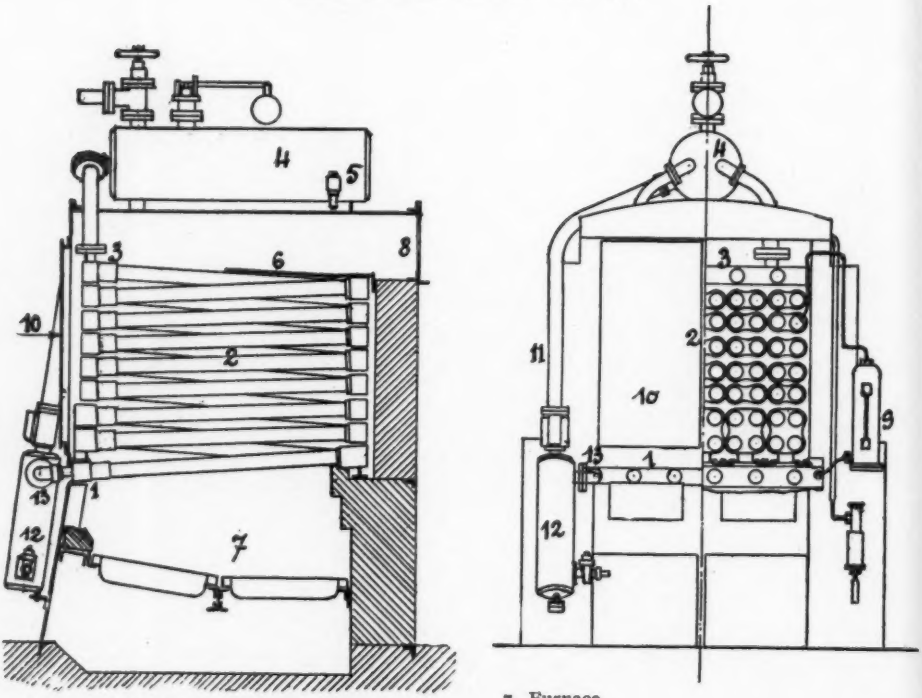
Fig. 17.




1. Feed collector.
2. Steam collector.
3. Tubes directly connected with feed and water collectors.
4. Connecting sleeves.
5. Tubes with sleeve, right side of element.
6. Tubes without sleeve, left side of element.
7. Front junction boxes.
8. Back junction boxes.
9. Threaded connecting sleeves for right-hand tubes at front boxes.
10. Safety rings on connections.

**Plate 6.**

Model with double elements.—1872–1875.




1. Feed collector.
2. Steaming elements, consisting of inclined tubes connected by junction boxes.
3. Steam collector.
4. Water and steam separator, bear-steam and safety valves.
5. Feed-water inlet.
6. Baffle on top of tubes.
7. Furnace.
8. Uptake.
9. Float box.
10. Front cleaning doors.
11. Downcomer.
12. Mud box.
13. Elbow connecting mud box and feed collector (1).

was not suppressed, however; it remained to overcome the resistance of the water through which the steam must force its way upward, but this was overcome by the two causes which already insured circulation in the simple elements: the water head on the collector and the different densities of steam and water, the effect of which, owing to the inclination of the tubes, could more easily take effect. Therefore, from that moment the production of steam was much more regular, and the water level could be kept notably higher without priming taking place. These are positive signs of an easier steam production. Moreover, keeping the boiler in proper condition is easier, since the tubes are completely emptied when it is blown out. With double elements a strong water jet introduced in the uppermost tube flows down to the blow-out cock, carrying away the non-adherent deposits it meets. It is then sufficient, in most cases, to remove two plugs only, the highest and the lowest, in order to clean an element formed of 18 or 20 tubes. The invention of double elements was, consequently, a real improvement.

This uninterrupted sequence of improvements, and especially the latest mentioned, had brought forward a new type of boiler sufficiently characteristic to induce Belleville to take a new patent, August 19th, 1872, "summing up and claiming all improvements carried out after twenty-two years of continuous work and researches." It is unnecessary to return to the description of these several improvements, the outcome of which has been noted already. The sketch (Plate 6) gives a sufficient idea of how the boiler had been transformed.

The boiler so constituted seemed to have reached its final shape, and, indeed, no important change modified its appearance for a few years. The inventor only applied himself to improving its working by means of small details and accessory features. In that direction it is necessary to quote the creation of the Belleville feed pump (patented August 18th, 1873), an important appendage to the boiler, the feeding of which it ensures in all cases.

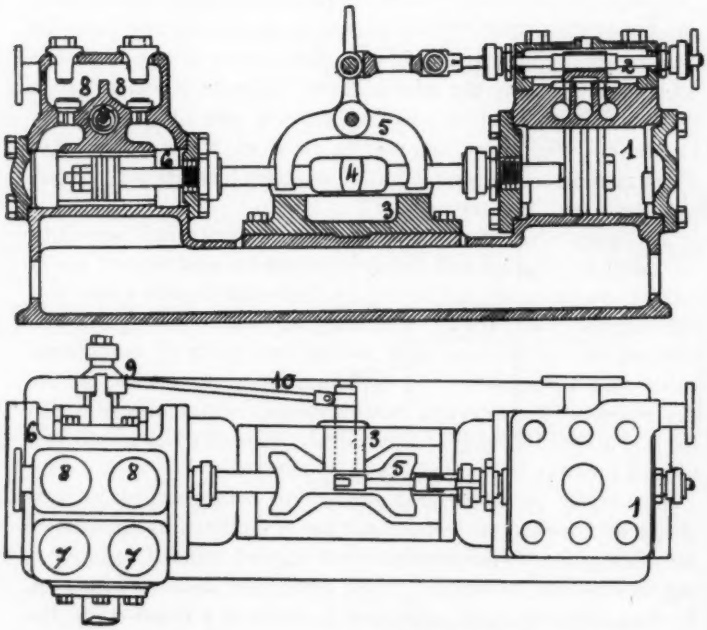
That feed pump, varied in shape, but with its principle unchanged since it was invented, is still in use, and the description

given by the inventor in his application for the patent still covers the present type of pump.

Fig. 18 illustrates the first feed pump of 1873. Fig. 19, which shows the latest model of it, demonstrates the transformations it has undergone.

This feed engine was distinguished by its general arrangement, quite new at that time, and especially by the peculiar feature which eliminates the resistance at the back of the water pis-

Fig. 18.




1. Steam cylinder.
2. Slide valve.
3. Base for fork (5).
4. Actuating sleeve, connecting piston rods.
5. Fork driving the slide-valve rod.
6. Water cylinder.
7. Suction valves.
8. Delivery valves.
9. Relief water cock.
10. Connecting rod, driving relief cock.

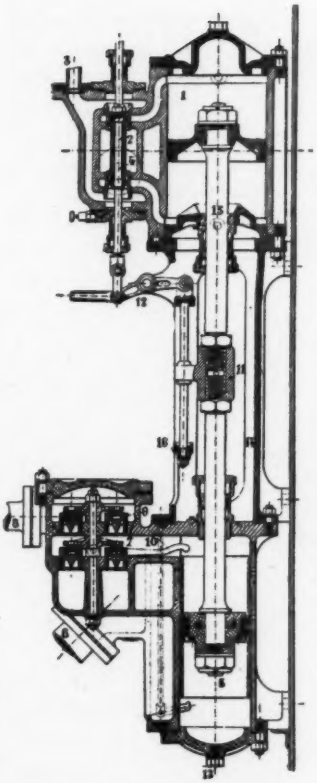


Fig. 19.

1. Steam cylinder.
2. Slide valve.
3. Steam inlet.
4. Steam exhaust.
5. Water pump.
6. Suction pipe.
7. Suction valves.
8. Delivery pipe.
9. Delivery valves.
10. Relief valve levers.
11. Sleeve connecting piston rods.
12. Lever driving slide valve.
13. Drain plug.
14. Foundation plate common to steam and water cylinders.
15. Cylinder drain cock.
16. Fiber ring.

ton at each end of its stroke, in order to facilitate its passing the dead point. This result is obtained by means of two exhaust ports opened by levers (9), Fig. 19, which are worked by the water piston as it nears the end of its stroke. In the original types (Fig. 18) the water exhaust was produced by a cock (9), acted upon by the connecting rod (10).

During the three years, 1872 to 1875, the six hundred and fifty Belleville boilers supplied to various industrial establishments testify to the increasing favor with which they were received.

The "Forges and Foundries of Bessèges" installed a battery of eight; the Société de la Vieille Montagne," having used them since 1868, ordered new ones as it enlarged its plant; the "Société Cockerill" and several shipyards fitted them on board ships; the French Navy continued their use in dockyards and on small boats. From 1872 to 1875 Belleville boilers were fitted on fifteen steam launches, a gunboat and two pumping boats, where the satisfactory results arrived at soon induced the Navy to undertake more important experiments, to which reference will soon be made.

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## Chapter III.

### MODEL HAVING MULTIPLE ELEMENTS AND ACCELERATED CIRCULATION. 1875-1894.

In the type last described, variations of water level which could not be wholly prevented by the working of the automatic feed regulator, sometimes caused priming into the upper collector and the separator, the dimensions of which were gradually increased.

It was then sought to send this water back to the lower collector through a blow-off pipe; thence the way was opened towards continuous circulation; indeed, the diameter of this blow-off pipe was gradually enlarged, as it was recognized that every new increase of its diameter permitted a greater variation of the mean water level, which meant that a greater amount of water could be carried away without inconvenience. When this diameter was made so large that all the water carried away could return to the lower collector, the inventor was led to induce and ensure a continuous upward travel of the water in an element, as well as the continuous downward movement of that water, mixed with fresh feed water, through this blow-off pipe to the lower collector. The "circulation" type thus created was defined in the patent taken June 24th, 1875.

In this new type, represented in Plate 7, not only was priming no longer harmful, but it had to be induced and rendered continuous to insure proper circulation; it was only necessary that

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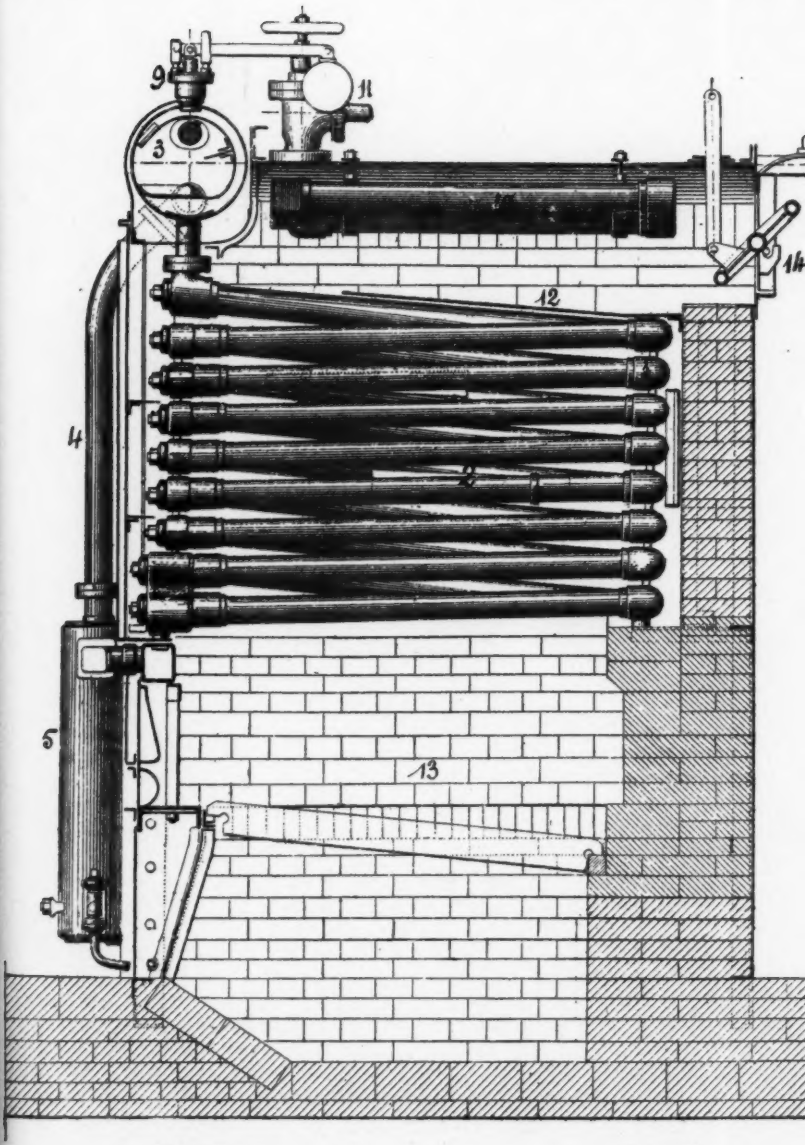
**Plate 7.**

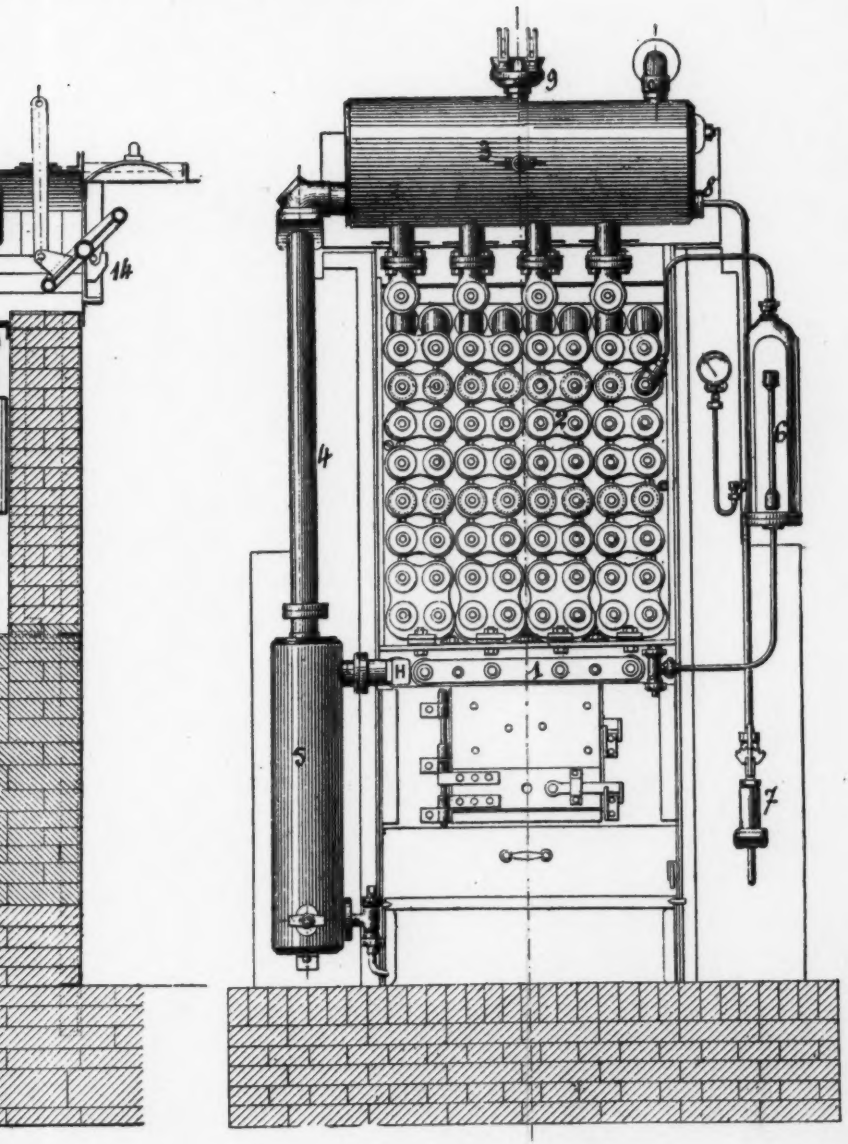
Model 1875, with double elements a




1. Feed collector.
2. Steaming elements, consisting of inclined tubes connected in coils by junction boxes.
3. Steam and feed-water collector and separator.
4. Downcomer.
5. Mud box.
6. Float box.
7. Graduated feed co
8. Water injecting no
9. Safety valve.

**Plate 7.**

uble elements and accelerated circulation.




ıd box.
ɔat box.
aduated feed cock.
ater injecting nozzle into collector (3).
fety valve.

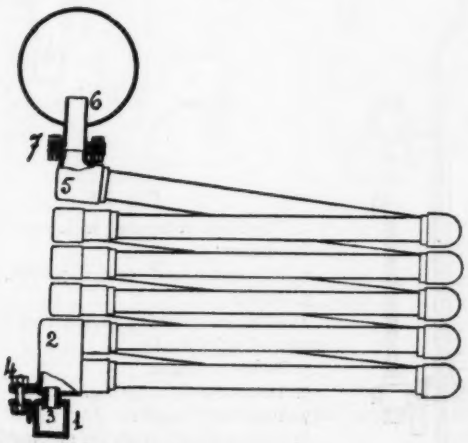
10. Steam drying tubes.
11. Steam valve.
12. Baffle on top of tubes.
13. Furnace.
14. Uptake.

some arrangement should allow the steam to be separated immediately from the entrained water when it reached the upper collector. This requirement gave rise to various forms of baffles or screens, arranged in the upper collectors, in order to purify the steam, which caused these separators to be termed *épurateurs*. This was the final type, and it only remained to improve the details, and in this process a series of changes gradually led to the present type.

These successive alterations will be but briefly pointed out; those that were preserved will be described later on, together with the type of the present day, mere mention being made of those which, for some reason, were abandoned.

First, the elements are set independent (patent October 6, 1876), *i. e.*, connected to lower collector and to separator by

Fig. 20.




1. Feed collector.
2. Lower junction box.
3. Conical nipple screwed into feed collector.
4. Securing bolt.
5. Elbow at top of element.
6. Steam delivery pipe to steam separator.
7. Connecting flange between 5 and 6.

joints easily disassembled. The annexed sketch, Fig. 20, shows this system of junctions, which is still in use.

The lower conical joint is designed to permit a small oscillation of the junction box, when, for instance, it must accommodate itself to the bending of a lower tube, which takes place

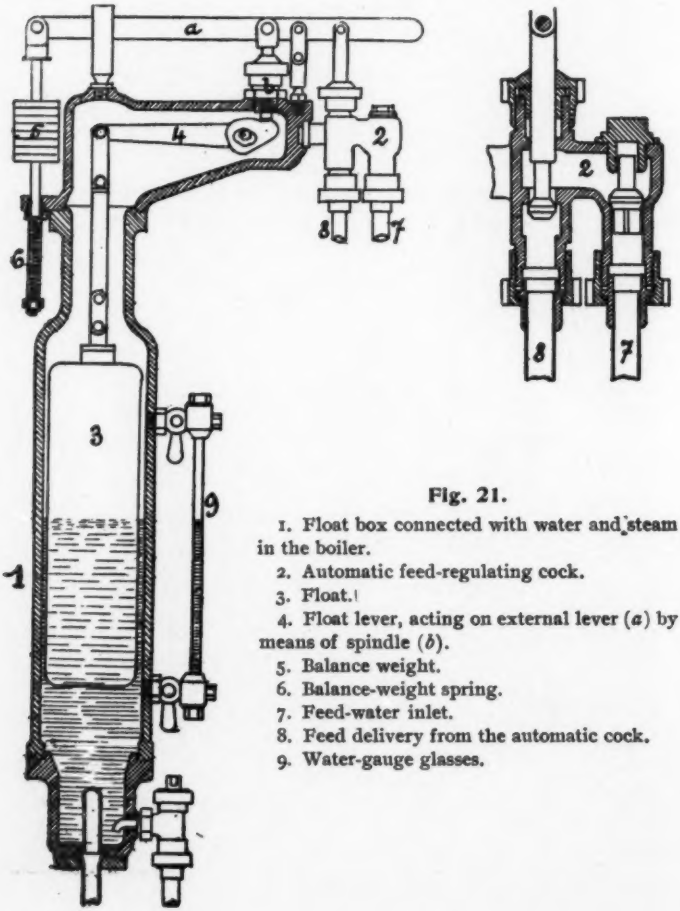


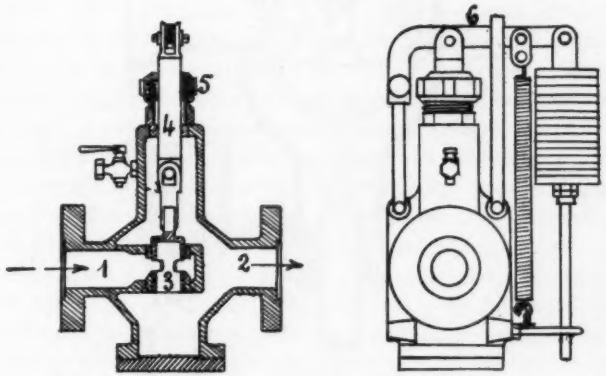

**Fig. 21.**

1. Float box connected with water and steam in the boiler.
2. Automatic feed-regulating cock.
3. Float.
4. Float lever, acting on external lever (*a*) by means of spindle (*b*).
5. Balance weight.
6. Balance-weight spring.
7. Feed-water inlet.
8. Feed delivery from the automatic cock.
9. Water-gauge glasses.

in all water-tube boilers, whatever the length and diameter of the tubes. For that purpose a slightly different angle is given to the cone surfaces in contact, the greater slope being on the inner cone.

Theoretically, the contact should only take place on a line by this method; but the uneven crushing of the interposed nickel sleeves compensates for the difference of slope, and the contact is wide enough to insure tightness. If a joint leaks it is always

Fig. 22.




1. Steam inlet.
2. Steam outlet.
3. Lantern valve.
4. Plunger loaded externally with a balance weight consisting of a permanent weight and spring.
5. Stuffing box.
6. Balance-weight lever.

possible to tighten it by screwing up the anchor bolt that fixes the junction box.

Feed injection into the steam is again provided for and improved in this type; the advantage of bringing very hot water upon the heating surfaces most exposed to the fire was never better realized, and at every new installation Belleville tried to raise that temperature still higher.

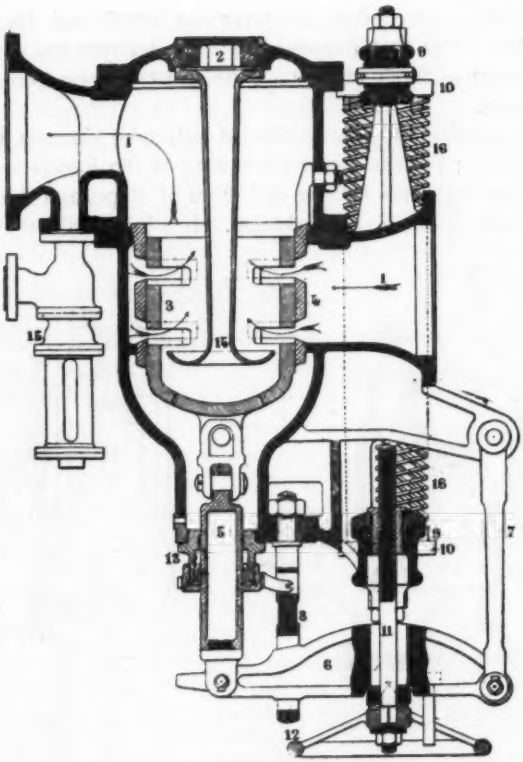



**Fig. 23.**

1. Reducing-valve chest.
2. Bonnet.
3. Valve.
4. Valve seat.
5. Plunger.
6. Lever.
7. Connecting rod.
8. Stop.
9. Crosshead on which springs (16) are attached.
10. Discs on spring ends.
11. Regulating screw.
12. Screw handle.
13. Plunger stuffing box.
14. Baffle.
15. Safety valve.

The same patent of October, 1876, includes the "mud box," intended to collect and retain, by decanting, the impurities contained in the feed water. It is a reminder of the earlier unsuccessful researches concerning the heating of feed water and the superheating of steam. Such questions were not then of actual importance, and the industries were little disposed to encourage experiments which seemed to them devoid of practical advantages. By this time the automatic feed regulator was also cleverly modified (Fig. 21); the cock worked by a float was replaced by spindles which could not stick or leak.

Soon after (December 22, 1878,) there appeared the first reducing valve (Fig. 22), which permitted the use of high-pressure boilers in connection with low-pressure engines. This apparatus, henceforth inseparable from the boiler, has been constantly improved, to the most recent model (Fig. 23).

One of Belleville's greatest anxieties was to obtain perfectly dry steam, and, despite the very good results already obtained, especially since the new type was created, he sought constantly to improve the process of separating and drying steam. This appears in the numerous patented arrangements for the internal baffling of the separators (steam drums). As before, all were based upon the utilization of the inertia of water, owing to which it continues to travel in the direction given by the baffles, away from the points where steam is collected.

It may be acknowledged today that all these researches would have been needless if the inventor had followed more decidedly the practice of increasing the area of the down-comer pipes. At the present time, as will be seen, nearly all these baffles have become useless, the down-comer pipes (two in each boiler) having been given a sufficient area to obviate the difficulty the baffles were intended to overcome. A bell-shaped screen is sufficient to break the upward flow of mixed water and steam from the generating elements, and to throw the water back into the circulation.

In considering the causes of priming, it must not be supposed that the water and steam are so intimately mixed when coming into a boiler steam chest that it is necessary, so to speak, to

filter the steam in order to separate it from the water. On the contrary, the water and steam instantaneously separate from each other upon reaching a space slightly greater than their combined volume. This sudden separation produces surface disturbances combined with more or less violent foaming, but it is only necessary, in order to deliver dry steam, to arrange the steam ports where these disturbances cannot reach them.

This disturbed condition, produced by violent ebullition, is much more liable to extend higher as the mass of water, lifted by the steam in passing through it, is greater, which explains why cylindrical boilers, where an enormous quantity of steam is produced along the furnace plates, under a large head of water, are subject to heavy priming despite the great volume of the steam space.

The same fact also controverts the too frequently stated assumption that a great area of water surface is favorable to the production of dry steam. Indeed, what takes place in water-tube boilers demonstrates the contrary, when the water level in the steam drum is half-way up, *i. e.*, when the water surface is maximum, priming is frequent, and is less when the water goes down and its surface area is reduced.

The question of drying steam effectually is thus confined, in any system of boiler, to the requirement that the delivery ports must be sheltered from the disturbance and upheaval of the water level caused by the steam and water suddenly parting from one another.

This explains the fact that Belleville boilers are free from priming; the water level in the steam chest being far below the top of tubes, no water is raised by the steam, and splashing is reduced to a minimum; besides, screens and baffles perfectly shelter the steam ports from accidental splashes, and the section of the ports is so small that a projection of water against them can do no harm.

Among the many improvements sought, no one seems to have interested Belleville so much as the possibility of practically feeding with sea water by means of purifying the feed water injected into steam. Coustê's works having confirmed his belief in

the insolubility of sulphate and carbonate of lime in water having a temperature of 155° C. (311° F.), he was encouraged to seek the solution of the problem he had set for himself since 1859. Nothing seemed to be more simple than to heat the water to such a temperature that the salts should be precipitated before admitting it upon the heating surfaces.

With that object, several types of feed injectors were invented by which water, projected in fine particles amidst the steam, as shown in Fig. 24, was to reach instantaneously the desired tem-

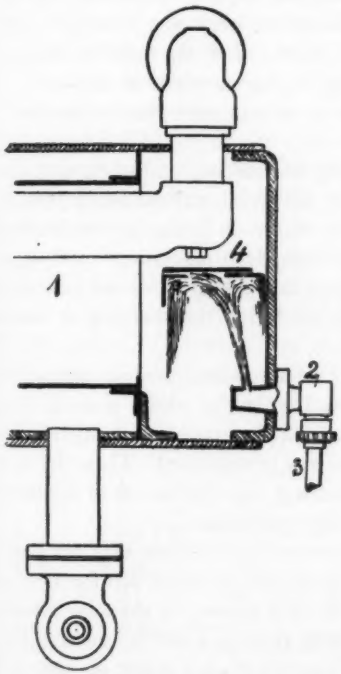



**Fig. 24.**

1. Steam collector and separator.
2. Feed-water injection fitted with non-return valve.
3. Feed-water inlet.
4. Baffle intended to break the feed-water jet.

perature, provided that the boiler pressure exceeded eight atmospheres.

The first results justified the hope of accomplishing the object sought. As has been stated in the official trial of the dispatch

boat *Actif* in 1869, after an hour's exclusive working with sea water, no adhesive scale was left in the tubes. In 1879, on the *Voltigeur*, where a specially interesting installation was made, as will be seen later, a similar trial was carried on for five hours and gave the same results. Continuous working with sea water was then attempted, but again it was soon shown that the simplest principles are often the most difficult to put in successful practice.

It has been said about the sea-water trial on the *Actif* that the precipitated salts formed abundant muddy deposits. These deposits, intimately mixed with water, were not wholly driven out by blowing off, and settled down, when the boilers were at rest, in thick mud at the bottom of tubes, where it caused frequent deterioration of the tubes most exposed to fire when working was resumed.

When sea water was used only for making up losses, and was mixed with the condensed water, the mud was evidently less in quantity, but, mixed with greasy materials from the condensers, it stuck upon the tubes and so formed an insulating coating as troublesome as solid scale. Thus the precipitation of the salts offered no other advantage than rendering the cleaning of tubes easier.

Even that advantage was, in certain circumstances, reduced to nothing, as it sometimes happened, when the whole mass of feed water did not instantaneously reach the required temperature, that the carbonate of lime alone was precipitated. Then the sulphate of lime formed by itself scaling deposits far more adhesive than those produced by both salts combined.

The only final result of all these experiments was to show that in case of need the Belleville boiler could be fed for several hours with sea water without inconvenience, on the sole condition that it be cleaned immediately afterward and before re-lighting fires. The advantage of bringing as hot water as possible into contact with the heating surfaces, which is now universally recognized, was also demonstrated in another direction.

This purifying that could not be carried out with sea water was, however, quite satisfactorily obtained for the usual feed

water in land boilers by this same process of feeding into the steam; the efficacy of the process being demonstrated by the fact that it has been adopted in all water-tube boilers now used in industrial works. Here again Belleville was a pioneer.

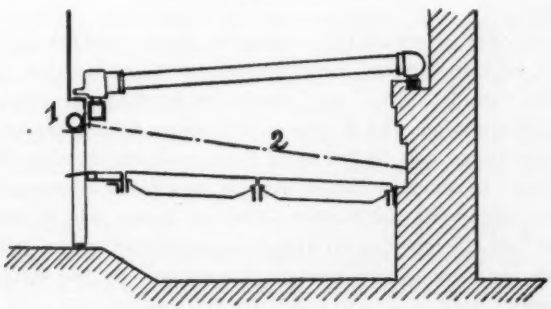
Returning to the continuous improvements of the new boiler with induced circulation, the clever departure may be pointed out which was patented December 1st, 1880. This consisted in fitting a blowing device to the furnace.

This device, blowing a jet of steam into the furnace in stationary boilers and of compressed air in marine boilers, produced an efficient mixing of the gases generated from the layer of burning fuel, which helped their combustion, especially in the case of soft fuels containing a high proportion of volatile substances.

The gaseous mass rising vertically from the grate through the steaming tubes, consists of streams traveling side by side, some containing combustible gas, some oxygen in excess. By mixing these streams together properly they combine in perfect combustion.

It may be objected that this blowing means consumption of steam, whether it be blown upon the grate direct or used to work a compressor; but if the benefit in vaporization exceeds the expense of blowing, the objection is void, and numerous experiments proved this to be the case.

Fig. 25.




1. Air collector. 2. Line of air jets.

On the other hand, in marine boiler plants the steam consumption in compressors can be reduced as much as desired by using a motor having a large piston area, because, as such engines always exhaust to a condenser, a small volume of steam is enough to make them work "on vacuum."

The steam or air jet is directed, as shown on Fig. 25, with a certain downward slope, so that it may not be carried away by the draft into the bundle of tubes previous to its having produced its effect.

Feed pumps were also improved by a new valve arrangement, patented October 6, 1883.

Another patent in July, 1884, sums up some new improvements: An appliance for saving the heat wasted in blowing off, placed on the feed delivery, the advantages of which can be understood without a description; a new arrangement of mud boxes; a new mode of connecting the boiler elements; a clever hydrometer cock, using the inertia of water having a circular movement.

At that time Belleville directed attention to the rapid decay of idle boilers, and suggested that they should be kept completely filled with water when they must remain idle, even a few days. In order to facilitate this operation, which he constantly recommended, and which has been universally adopted, he fitted on the top of his boiler a small air cock through which the contained air could escape, and by which the filling of the boiler could be verified.

Until 1889, when all the successive improvements since 1875 which were recognized as efficient were combined on a boiler termed "model 1889," the details of construction were given especial attention, with a view to lightening the marine and transportable types, and, at the same time, to strengthening the connections; to securing longer service from the stationary type by strengthening the parts most liable to decay, and to obtaining better fuel efficiency in all types by arranging grate bars judiciously and by giving proper dimensions to the combustion chamber.

In March, 1888, an arrangement was patented (illustrated in

Fig. 26), by which the feed pump exhaust was led into the feed suction ; it was termed an " ejecto-condenser."

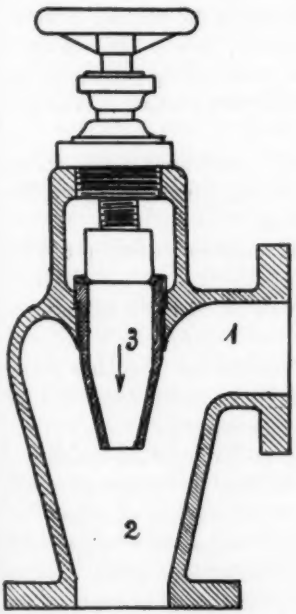



**Fig. 26.**

1. Water suction to ejecto-condenser.
2. Water delivery to pump.
3. Nozzle through which exhaust steam is projected into water.

The economy produced by this apparatus was undeniable, as the thermal units contained in the weight of steam introduced in the feed engine were totally transformed into work, either in driving the pump or heating feed water.

It is much to be regretted that this feature had to be abandoned on account of oil being carried from the cylinder into the feed water.

Finally, May 3, 1889, Belleville took a new patent for " improvements to his system of boiler," which summed up all the advantages of the latest type, called "1889 type."

The best way to illustrate the basis of the problems sought by the inventor, and the means through which he had solved it,

is to quote some extracts of the memorandum annexed to his application for a patent:

"The safety that can practically be realized against explosions is only obtainable by reducing to a minimum the volume of water contained in the whole body of a boiler; this is the reason I have rejected all additional vessels or tanks giving greater water capacity as contrary to the principle of safety which is, and has always been, my essential object.

"On the other hand, the necessary conditions for a steam generator, especially of the water-tube type, intended to render long and safe services, are the following:

"1st. The expansion of all parts exposed to the action of heat must be perfectly free. * * *

"2d. All parts of heating surfaces must be easily accessible, both inside and outside. * * *

"My numerous experiments have shown me that any boiler where the inside surfaces of the tubes is not easily accessible for cleaning is certain to decay more or less rapidly."

In passing, let us point particularly to this opinion, which was based upon the experience gained during the years when the Belleville boiler was not cleanable; it contains the strongest argument against small-tube boilers, and cannot be charged with having been formulated for the sake of argument alone.

"3d. Calcareous deposits must be precipitated in parts of the boiler sheltered from the direct impact of flame or hot gases, in order to avoid the adhesive deposits which are necessarily produced upon heating surfaces *whatever the circulation may be in the tubes.* Rapid circulation hinders, to a certain extent, which varies with the nature of water, the adherence and gradual thickening of scale upon heated surfaces; but to guarantee its suppression is a serious mistake, which was demonstrated by numerous experiments in which the normal velocity of the water current was very great.

"4th. In order to obtain a good efficiency of heating surfaces and a perfect preservation of tubes, *with an active combustion and abundant production of steam*, a boiler must be so arranged that an active stream of water and steam, in a state of forced

circulation, shall constantly pass through each of its steaming elements.

"5th. Regularity in pressure and feeding is an essential condition for the good working of a boiler. But it is especially difficult to secure this in a safety boiler which, by its very nature, is more sensitive to variations in the activity of combustion and steam consumption. It is possible to approach that essential condition, to a certain extent, by adding to the boiler, water tanks of a sufficient capacity to form, so to speak, a heat fly wheel (*volant de chaleur*). But such a solution is in absolute contradiction to the object I always had in view, viz: to reduce to a minimum the dynamical effect of explosions by minimizing the volume of water employed; it is, indeed, incompatible with safety.

"Having always refused to sacrifice safety, which was the essential object of my works, from the very beginning, I have come to the conclusion that regular pressure and feed must be obtained through automatic apparatus regulating the water inlet and the activity of combustion according to working conditions.

"My 1889 type of boiler involves the practical realization of the very diversified conditions above enumerated:

"1. (*a*) To permit the free expansion of tubes, I have divided each boiler into elements or units independent from each other; each of these elements has the shape of a flat coil, forming a virtual spring, eminently elastic, and fitted to meet the expansions and contractions that necessarily take place in service.

"(*b*) I have banished ordinary cast iron from all constructive parts of the boilers and their casings, using only iron, cast steel and malleable cast iron, which metals can be wrought. Cast iron has been retained only in some accessory parts outside the boilers, such as float boxes, stop valves, &c., which are not exposed to fire nor to such high temperatures as might cause them to break.

"2. Front smoke doors permit cleaning the outside of tubes, the moderate length of which permits their being cleaned inside.

"The outside cleaning of tubes is easily done with brushes and scrapers introduced through the spaces between junction boxes. It can be carried out under way, either with the above tools or with a steam hose.

"3. The deposits contained in feed water are precipitated in a muddy state, owing to the feed inlet being situated in the separator.

"4. The only practical arrangement that secures forced circulation in a boiler (a very important condition for good working) is the combination of the three following parts:

(*a*) Steaming elements forming a single and continuous canal from bottom to top.

(*b*) A collector, receiving the mixture of water and steam from the elements, together with the feed water.

(*c*) One or more external pipes connecting the collector to the lower part of the elements, with or without a mud box.

"5. Regular feeding is obtained by the use of an automatic regulator * * * . I have taken advantage of the sensitiveness with which steam pressure follows variations in the activity of combustion, to construct a regulator acted upon by variations of steam pressure and working on a draft register."

This lengthy quotation is given because the description still covers the present boiler, in which not only the principles, but the general arrangements and details of the "1889 type" have been preserved, the only difference being in the economizer added to it in 1894.

The numerous trials that had marked the period previous to the creation of the 1875 type had somewhat checked, especially in large marine installations, the impulse that led the industrial world towards high-pressure water-tube boilers, almost exclusively represented by the Belleville. But, after the creation of a type with accelerated circulation, fears soon disappeared and various industries decidedly adopted the new boiler which thereafter combined its own advantages with those that had previously kept tank boilers in favor. The French Navy, taking the lead in this case as in many others, had noted with interest the successive improvements upon the original apparatus tried as early as 1854 on the *Biche*, and, foreseeing that the new type of the Belleville boiler would lead to a final success, it was decided in 1879 to try it in the dispatch boat *Voltigeur*, of 1,000 H.P.

That the French Navy was taking interest in the improve-

ments of the Belleville boilers, is amply demonstrated by the numerous instances in which these boilers were installed, viz:

1854. Corvette *Biche*. First installation.
1856. Corvette *Biche*. Second installation.
1861. Dispatch vessel *Argus*. First installation.
1863. Transport ship *Vienne*. First installation.
1865. Three launches, 30 feet long. First application on launches.
1866. Auxiliary services on yacht *Jerome Napoleon*.
1867. Pumping barge.
1867. Dispatch vessel *Argus*. Second application.
1867. Forty-three launches.
1867. Two gun boats.
1868. Ten gun boats.
1868. Forty-seven launches.
1868. One torpedo boat.
1868. Dispatch vessel *Actif*. (Was present at the opening of the Suez Canal.)
1869. Imperial yacht *Hirondelle*, which was used as a scout during the war of 1870.
1869. One gun boat.
1869. Four launches.
1870. Twenty-one launches.
1871. Thirty-four launches.
1872. Two launches.
1873. Two gun boats.
1873. Five launches.
1873. Two pumping boats.
1873. One torpedo boat.
1874. Eight launches.
1875. Seven launches.
1876. One torpedo boat.
1876. One launch.
1877. Four launches.
1878. Nine launches.
1879. Four launches.
1879. The *Farey*, gun boat.
1879. Dispatch vessel *Voltigeur*.

As it became more exacting, the Navy would not undertake further installations—a prudent decision, which cannot but be approved, but which was not always adhered to—before being assured that the proposed apparatus would be satisfactory, not only during trials, but also on extended service. Therefore the *Voltigeur* was commissioned for a distant cruise as soon as she was finally accepted.

As this experiment was to decide the future of the Belleville boiler in the Navy, it is interesting to note the appreciative reports that followed it.

The trials were the more interesting because they answered a question already asked at that time, and which the British Admiralty again propounded twenty-two years later, viz: whether Belleville boilers offered a real advantage over cylindrical boilers. These trials were, indeed, carried out comparatively with those of a similar vessel, the *Chasseur*, fitted with cylindrical return boilers, then exclusively used in the Navy; and it is a remarkable coincidence that the judgment formulated at that time by the Committee agrees with that of the later English Boiler Committee, granting superiority to the Belleville boilers for identical reasons.

In its report, after pointing out and describing the clever arrangement of the boilers and their appurtenances, the committee expresses itself in the following manner on the subject of recognized advantages:

"*Raising Steam.*—Is remarkably quick. Several trials were made on this point: Upon lighting fires in the six boilers simultaneously, steam appears after fifteen minutes; at the same moment, the cocks to cylinder jackets are opened in order to warm up the engine; eight minutes later the pressure at the engine valve is four atmospheres, and it is then possible to move the engine to and fro, which takes two minutes; it is then ready to start. It takes, therefore, twenty-five minutes after lighting fires to get thoroughly ready, and fifteen minutes later it can be started ahead at 200 revolutions. This advantage is very important, and, for the *Voltigeur*, it means a gain of nearly an hour over the time required to get the *Chasseur's* engines ready.

"*Stopping.*—When the engine is suddenly stopped, pressure tends to go up very rapidly; the safety valve or steam pipe then protects the engine from all danger, but it is better to moderate this rise, which causes a loss of fresh water. It is then necessary to close the ash pits, open the front doors and start the feed pump. It has thus been possible sometimes to keep the pressure at a stand still; feeding with the donkey pump has the advantage of utilizing the furnace heat.

"*Drying Steam.*—The features for drying steam are remarkably combined and always worked quite satisfactorily.

"When it happened accidentally, under regular working conditions, that a little water was carried into the main pipe, the general separator always stopped it, returning it to the hot well through the automatic blow-off, and the engine never felt it.

"On starting, only insignificant clacking took place in the cylinders, due to condensed steam. Under way, very great and sudden changes of speed (40 to 50 revolutions, for instance) were required to cause priming, very moderate indeed and of short duration. This took place more frequently when speed was being reduced.

"It must be acknowledged, as a whole, from this point of view, that the boilers on the *Voltigeur* present very remarkable qualities.

"*Purifying Feed Water.*—Feed water seems to be purified with certainty. This was demonstrated by the use of lime water during the trials. It was, indeed, stated, when examining the boilers, that neither the tubes nor the feed collectors contained any noticeable deposits. On the other hand, the top of the flat parts of baffles in separators was coated with a black adhesive substance $\frac{1}{4}$ inch thick, which was a mixture of calcareous salts and 'iron soap.' Therefore impurities separated from the feed water are thoroughly precipitated, partly inside the separators.

"In the mud boxes a large amount of similar deposit was found. A part adhered to the sides and formed a funnel, the point of which was somewhat below the orifice of the internal blow-off pipe. The rest had the appearance of a somewhat compact concrete, filling the bottom of the mud box, up to the blow-off orifice.

"*Safety.*—Very important and undeniable advantage. The most serious break down that could happen in the boilers of the *Voltigeur* is the bursting of a tube. This is unlikely, owing to special arrangements (fusible plugs) by which the danger should be signalled in time. In any case it would not be more dangerous than the rupture of one of the *Chasseur's* tubes through want of water.

"*Comparative Lightness.*—The weight of the *Voltigeur* boilers, piping excluded, is 53.2 tons. The weight of the *Chasseur* boilers, in the same conditions, is 71.8 tons.

"The ratio of these weights is .74.

"The maximum steam production per hour is:

"On the *Voltigeur*, 8.077 tons at natural draft.
9.574 tons at forced draft.

"On the *Chasseur*, 6.593 tons at natural draft.
9.571 tons at forced draft.

"The ratio is .82 at natural draft; with forced draft the productions are equal. Considering only the natural draft, the weight of the *Voltigeur* boilers compared with their power is only $.74 \times .82 = .607$ of the weight of the *Chasseur* boilers.

"*No Priming.*—A very great advantage in favor of Belleville boilers.

"*Comparison with the Chasseur Boilers.*—To sum up, leaving aside secondary qualities and defects, the following must be advocated in favor of the *Voltigeur* boilers: Safety, lightness, quick raising of steam and absence of priming. This last quality, united with a great facility for establishing and varying the pressure, gives to the *Voltigeur* machinery a suppleness and elasticity that the *Chasseur* machinery is far from possessing, and by which the Committee was deeply impressed. As disadvantages of the *Voltigeur* boilers there must be quoted: Their inferior fuel efficiency, complicated construction and more difficult working.

"The advantages are of the utmost importance and can be immediately realized; the drawbacks will be brought to light by current practice. It is difficult to establish the balance between them from the results of these trials only; but it is beyond doubt that the question deserves a thorough examination. It is

fair to admit that the Navy will derive benefit from the experiments on the *Voltigeur*.

"*Conclusions.*—The boilers are strongly and carefully built; their special features for drying steam and purifying feed water, also for automatically regulating the condition of steam, are very eleverly contrived.

"All their parts worked in a very satisfactory manner during the trials.

" When formulating these conclusions the Committee does not mean to express a final opinion on the *Voltigeur's* boilers; it believes that an accurate study of their working in current service must be a natural continuation and necessary completion to these trials. Many questions can only be decided upon in that way."

These advantages, thus acknowledged seventy-four years ago, are just those necessary and sufficient to fit a boiler for all services, and especially for marine work. They are, indeed, those which all inventors in recent years have advocated in favor of their boilers without seeking any others.

During the trials a five-hours' test on feeding with sea water was carried out, as already described, and gave satifactory results.

It remained to ascertain how the new boilers would behave in service. The report of the captain of the *Voltigeur*, after two years' cruising, gives information on that point by describing the condition of the various parts of the boilers.

" *Steaming Elements.*—Boiler tubes are in good condition. They seem to have undergone no deterioration, and it is not likely that any of them will have to be replaced in the near future. Junction boxes are also in good condition. * * * All tubes have been scraped and thoroughly cleaned three times during the cruise.

" *Feed Collectors.*—Feed collectors are in good condition, and contain very little scale.

" *Steam Separator.*—The steam collectors and feed water purifiers, the object of which is instantaneously to precipitate calcareous salts in a pulverulent state, work well and are in good condition.

"*Mud Boxes.*—Mud boxes are in good condition and work well,

as is apparent from frequent inspections, when greasy and muddy deposits, mixed with salt, were found only in the bottom, up to the blow-off pipe.

"*Automatic Feed Regulators.*—These, as well as all feeding apparatus, are in good condition, and, up to the present day, have worked well.

"*Iron and Brick Casings.*—The iron casings of the boilers, and also the brick work, are in very good condition, and do not seem to have suffered in any of their parts.

"From the above it can be affirmed that, at the present moment, the *Voltigeur* boilers are in as good a condition as at the beginning of the cruise, and it may be expected that they will preserve the same condition for a long time to come.

"I am therefore led to state, after two year's commission, that the *Voltigeur* boilers have fulfilled all the conditions already enumerated by the Trial Committee, viz:

"Safety and strength.

"Quick raising of steam.

"Absence of priming and of solid substances in the cylinders.

"Facility in fixing and varying the pressure.

"Easy repairing and cleaning.

"Economy of fuel."

The experiment was thus decisive and quite in favor of the new boiler. Therefore its installations soon became more numerous and important, as shown in the following list:

| | | | I.H.P. |
|---|---|---|---|
| 1882 | *Milan*, | Dispatch Vessel, | 3,800 |
| 1883 | *Hirondelle*, | Dispatch Vessel, | 2,100 |
| 1883 | *Crocodile*, | Gunboat, | 450 |
| 1885 | *Admiral-Rigault-de-Genouilly*, | Cruiser, | 2,100 |
| 1887 | *Actif*, | Advice Boat, | 400 |
| 1888 | *Alger*, | Cruiser, | 8,000 |
| 1889 | *Caudan*, | Advice Boat, | 600 |
| 1890 | *Abervrac'h*, | Tug Boat, | 170 |
| 1890 | *Léger*, | Torpedo Advice Boat, | 2,200 |
| 1890 | *Lévrier*, | Torpedo Advice Boat, | 2,200 |
| 1890 | *Latouche-Tréville*, | Armored Cruiser, | 8,300 |

| | | | I.H.P. |
|---|---|---|---|
| 1890 | *Chanzy*, | Armored Cruiser, | 8,300 |
| 1890 | *Admiral Charner*, | Armored Cruiser, | 8,300 |
| 1890 | *Brennus*, | Battleship | 14,000 |
| 1891 | *Amiral-Tréhouart*, | Iron-Clad Coastguard, | 7,500 |
| 1892 | *Bruix*, | Armored Cruiser, | 8,800 |
| 1892 | *Bugeaud*, | Cruiser, | 9,000 |
| 1892 | *Descartes*, | Cruiser, | 8,500 |
| 1893 | *Bouvet*, | Battleship, | 14,000 |
| 1893 | *Pothuau*, | Cruiser, | 10,000 |
| 1893 | *Pascal*, | Cruiser, | 8,500 |
| 1893 | *Galilée*, | Cruiser, | 6,600 |
| 1894 | *Catinat*, | Cruiser, | 9,000 |
| 1894 | *Charlemagne*, | Battleship, | 14,500 |
| 1894 | *Lavoisier*, | Cruiser, | 6,600 |

Thus, since the *Voltigeur* until the *Lavoisier*, which closes the list of applications of that type, 26 ships of 165,000 aggregate horsepower were fitted with Belleville boilers — gradually equipped with the new features that practice demonstrated to be necessary.

Foreign naval powers watching the change that was taking place in France and the final abandonment of cylindrical boilers, were compelled by the evident inferiority of their own fleets, due to the maintenance of these boilers, to adopt in their turn water-tube boilers, then almost exclusively represented by the Belleville type, which was and still is the one sanctioned by longest experience.

The Russian Navy first followed the lead of France with the following installations:

| | | | I.H.P. |
|---|---|---|---|
| 1886 | *Minine*, | Armored Frigate, | 6,000 |
| 1889 | *Groziastchy*, | Gunboat, | 2,000 |
| 1889 | *Marevo*, | Imperial Yacht, | 200 |
| 1890 | *Strela*, | Imperial Yacht, | 1,600 |
| 1891 | *Gremyaschy*, | Gunboat, | 2,500 |
| 1891 | *Otvajni*, | Gunboat, | 2,500 |
| 1893 | *Standard*, | Imperial Yacht, | 15,000 |
| 1893 | *Tzarewna*, | Imperial Yacht, | 800 |

The British Navy, although it did not, perhaps, doubt the value of the new boilers, was rather kept back by the fear of causing harm to domestic makers and metallurgists, who were already starting a fight against them in the press. It was led in turn, however, to abandon cylindrical boilers, which from 1890 to 1893, after serious mishaps, had put several ships in a very bad position. After trials on the 3,500 H.P. torpedo-catcher *Sharpshooter* in 1893, during which the boilers were submitted to very severe and exhaustive tests that proved their strength and endurance, the British Admiralty adopted them for all fighting ships, and in that year (1893) fitted them on the 25,000 H.P. cruisers *Powerful* and *Terrible*, which were soon followed by fifty-eight ships of different classes, fitted with the new type soon to be described, which appeared in 1894, thus giving a total of 912,800 H.P.

In 1884, long before the British Navy decided to try Belleville boilers, and two years before the Russian Navy, the "Compagnie des Messageries Maritimes" gave them a place in the mercantile marine and tried them on the 1,900 H.P. cargo-boat *Ortegal*. After two years' experiment, they adopted them on all their new mail steamers:

| | | | H.P. |
|---|---|---|---|
| 1886 | *Sindh*, . . . . | Mail Steamer, . . | 2,900 |
| 1888 | *Australien*, . . . | Mail Steamer, . . | 7,200 |
| 1889 | *Polynésien*, . . . | Mail Steamer, . . | 7,200 |
| 1890 | *Armand Béhic*, . . | Mail Steamer, . . | 7,200 |
| 1891 | *Ville de La Ciotat*, . . | Mail Steamer, . . | 7,200 |
| 1892 | *Ernest Simons*, . . | Mail Steamer, . . | 6 000 |
| 1894 | *Chili*, . . . . . | Mail Steamer, . . | 6,000 |

Installations were further continued with the new type that superseded the model just described.

Finally, in 1893, the "Cie. des Chemin de fer de l'Ouest" fitted these boilers on the first of the eight steamers it had built for the Dieppe-Newhaven service; the other seven were fitted with the 1894 type.

During the same period industrial applications were multiplied, and over 2,000 boilers supplied.

It is not superfluous to point out that the favor enjoyed by the new boiler in the industries was justified by the services it rendered, and not the result of a temporary fancy. The opinion of some manufacturers upon boilers they had been using for over twenty years will certainly serve as a more eloquent demonstration of this fact than any theory.

The firm "Chaix," central printing works for railways, having used Belleville boilers since 1862, ordering two others in 1872 and two in 1881, wrote in 1896 that the boilers supplied fifteen years earlier were still working entirely satisfactorily. This is not a platonic testimonial, since, in June, 1901, the same firm again ordered two new boilers.

The manager of the "Grands Magasins du Louvre," in Paris, was pleased to write to Messrs. Belleville, under date of August 13, 1900, that two years after his boilers had been at work he had been pleasantly surprised at their easy manipulation, maintenance and safe working, but that after twenty years this satisfaction was still uninterrupted.

On February 19, 1902, Jules Jaluzot, manager of the "Grands Magasins du Printemps," in Paris, wrote that he was extremely satisfied with his eight Belleville boilers, adding that three of them were soon to undergo their decennial test; four others would reach their twentieth year of service in 1903, and that, during this long period of continuous working, he never had met with the least accident.

Numerous testimonials could be quoted in the same manner, and to these might be added the very long list of Belleville boiler plants having worked over twenty years, but it is sufficient to have demonstrated in certain cases that these boilers have been capable of giving full satisfaction during more than twenty years, so that it must be admitted that they should not be too severely criticised in cases where such long services could not be obtained.

The persistent use of Belleville boilers by some manufacturers in successive installations over periods of twenty and even thirty years, is an undeniable proof of the very good services they

have rendered. Some examples of such successive installations made in the same works are here given:

Mines & Zinc Foundry—Société de la Vieille Montagne—1868–1898, 49 boilers; aggregate steam production, 52.93 tons per hour.

Compagnie des Fonderies et Forges de Terrenoire, La Voulte et Bessèges—1872–1887, 41 boilers; aggregate steam production, 30.2 tons per hour.

Compagnie Houillierè de Bessèges—1875–1897, 13 boilers; aggregate steam production, 11.5 tons per hour.

Compagnie des Minerais de Fer Magnétique de Mokta-el-Hadid—1876–1895, 11 boilers; aggregate steam production 9.2 tons per hour.

Compagnie Française des Métaux (anciens Etabl'ts Laveissière)—1877–1898, 13 boilers; aggregate steam production, 25.25 tons per hour.

Société des Hauts Fourneaux et Forges de Denain & Anzin—1879–1891, 15 boilers; aggregate steam production, 33.2 tons per hour.

Les Fils de Peugeot Frères, Valentigney—1879–1898, 9 boilers; aggregate steam production, 18.5 tons per hour.

Austro-Hungarian State Railways—1881–1890, 12 boilers; aggregate steam production, 20.7 tons per hour.

Société Anonyme des Fabriques de Mieres (Spain)—1882–1902, 9 boilers; aggregate steam production, 13.3 tons per hour.

Forges de l'Adour, Boucau—1884–1898, 16 boilers; aggregate steam production, 37.1 tons per hour.

Compagnie des Mines de Vicoigne & Nœux—1888–1899, 11 boilers; aggregate steam production, 27.8 tons per hour.

Grands Magasins de la Belle Jardinière, Paris—1869–1901, 8 boilers; aggregate steam production, 9.15 tons per hour.

Weibel & Co., cellulose manufacturers, Novillars—1886–1892, 10 boilers; aggregate steam production, 23.45 tons per hour.

Balsan & Co., cloth manufacturers, at Chateauroux—1868–

1896, 13 boilers; aggregate steam production, 16.2 tons per hour.

Société Anonyme d'Eclairage et de Force par l'Electricité, Paris—1889–1899, 19 boilers; aggregate steam production, 36.7 tons per hour.

Le Petit Journal, Paris—1867–1896, 6 boilers; aggregate steam production, 7.85 tons per hour.

In such data as the above lies the best reply to the criticisms created and fostered by the fierce competition which soon arose. These criticisms have remarkably developed during the recent years, in which so many new boilers have been exploited, although the unceasing improvement of Belleville boilers should have protected them against the attacks of those to whom they had shown the way.

An impartial examination of other systems may show that certain of them, while they are by no means superior, offer in the same degree some of the advantages by which the Belleville boilers are distinguished; but no one system offers, united in a single apparatus, the same maximum total of good qualities together with the same minimum sum of defects.

Whatever motives may have given rise to it, adverse criticism only stimulated the Belleville firm in their search for further improvements, and a new series will now be illustrated, and among them the feature called the "economiser," which rendered the efficiency of the Belleville boiler superior to that of any other type.

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## Chapter IV.

### BOILER WITH INDUCED CIRCULATION, FITTED WITH ECONOMISER.

**1894-1903.**

In 1891 Belleville could look back with pride at his achievements since his first 1850 patent; but he was also compelled to recognize that these forty years of continuous fight, during which he had overcome so many unforeseen obstacles, though they could not exhaust his inventive genius, had mastered his physical strength. Now, as he could no longer devote to the import-

ant firm he had founded the required activity, he submitted to taking a well deserved rest.

The fear of idleness had alone prompted Belleville to wear out his strength to the end, for the successor to whom he entrusted his work, Louis Delaunay Belleville, his son-in-law, late fellow of the Polytechnic School and of the French School of Naval Architecture, had long been his fellow worker, and in that capacity having contributed largely to the success of the latest installations, was thoroughly prepared for the difficulties of the task which now rested upon him.

The first departure due to the new directorship consisted in replacing the separator ends, made of flat steel plates, by spherical molded steel pieces. The advantage of this change, due to the greater facility offered to the downward movement of the water, has been pointed out. It, moreover, affords greater strength and economy of space. The arrangement of baffle plates in separators was then simplified, and the Belleville feed pumps were improved (Delaunay Belleville patents of November 30th, December 9th, 1892; February 9th and December 1st, 1893).

Another clever improvement was made at that time, which insured safety by automatically closing the plugs on junction boxes, in way of every tube. Up to that date, the joint on these plugs being external, accidents had only been avoided because of the excellent quality of material employed and to the very ample size of the bolts that fixed the plugs; still the front doors were never opened while the boiler was under pressure without some apprehension, as a concealed defect might have existed in any one of the bolts.

But a further advance was soon accomplished by the creation of the "economiser," patented July 20, 1894, which constituted a new type known as "Model 1896."

The economiser is, in fact, a feed-water heater which utilizes the waste heat from the hot gases, and especially that heat which is still available in those gases that are incompletely burned through defective combustion.

This new combustion or re-inflammation of gases cannot take

place if the economiser is closely superposed upon the steaming elements. Therefore an additional combustion chamber was fitted between the steaming and economiser tubes, where the gases could be thoroughly mixed and their combustible elements be combined. Such a combustion chamber is required for the efficacy of the apparatus. The above explains the failure of so many devices designed to utilize only the waste heat from the hot gases without providing for a combustion chamber in which the proper admixture of the gases is assured to produce a second and complete combustion.

The very noticeable rise in the temperature of feed water that can be obtained without cost, through an economiser arranged as above described, must evidently result in an increase of the boiler efficiency, which amounts to the value of the ratio

$$\frac{(606.5 + 0.305\,T) - t_i}{(606.5 + 0.305\,T) - t_e}$$

(French thermal units and temperature expressed in degrees centigrade.)

Where $T$ is the temperature of steam, $t_i$ the temperature of feed water entering the economiser, and $t_e$ that of water leaving the economiser.

The average rise of temperature is from 60 to 120 degrees C (108 to 216 degrees F.), which should increase the efficiency by 10 to 20 per cent. But it must be observed that the higher figure is due to the re-inflammation of gases rather than to utilizing the waste heat; it is, therefore, the consequence of defective management of the fires, which means inferior boiler efficiency, so that the benefit of 20 per cent. applies to unsatisfactory working conditions. It exists, however, since the re-inflamed gases would have been lost, and, considering that the fires are, as a rule, badly manipulated, it may be said that the economy due to the presence of economisers, although it is not 20 per cent. of the normal coal consumption, still amounts to 20 per cent. of the actual consumption.

Comparative evaporation trials with and without economisers will give a minimum benefit in favor of the latter, because, the

fires being properly handled in both cases, the economisers will only receive a minimum amount of heat due to re-inflammation.

Numerous experiments have been made by which increased efficiency was shown to result from the use of economisers. Experiments on a marine type of boilers will be first mentioned.

*Official Trials.*—The first series of official trials was carried out at the Belleville works under the supervision of engineers from a foreign Navy, the second under the supervision of French naval engineers.

In all trials the same quality of fuel, ordinary Cardiff coal, was used. It was carefully weighed before being brought to the boilers. Feed water was measured in graduated tanks. Observations were taken every half hour, and thus checked by each other.

Previous to escaping into the open air the steam had to pass through a general separator, where the water carried away was separated from it. This amount was then deducted from the total steam production. During all trials it was quite trifling (under 1 per cent.).

Temperatures of smoke and water before and passing through the economiser were also noted.

The data thus obtained are given in the following table. Trials carried out by the French Navy are marked thus †. Those made by a foreign government are marked thus *.

| 1 \| 2 Steam produced | | 3 | 4 \| 5 Gas temperature. | | 6 | 7 |
|---|---|---|---|---|---|---|
| Kilos. per sq. meter (lbs. sq. ft.) of grate per hour. | Per unit of coal by weight. | Coal burned, kilos per sq. meter (lbs. sq. ft.) of grate per hour. | Before passing through economiser. | After passing through economiser. | Rise in temperature of feed water. | Date of trial. |
| *Kilos.* (*Lbs.*) | | *Kilos.* (*Lbs.*) | *Degrees,* C. (F.) | *Degrees.* C. (F.) | *Degrees.* C. (F.) | 1896. |
| †713 (146) | 10.23 | 69.7 (16.27) | 317 (603) | 185 (365) | 72.7 (130.9) | Oct. 20 |
| *846 (173) | 9.74 | 86.9 (17.8) | 369 (691) | 206 (403) | 73.3 (132) | Sept. 16 |
| †934 (191) | 9.46 | 98.7 (20.21) | 374 (705) | 221 (430) | 74.4 (133.9) | Oct. 17 |
| *1,107 (227) | 9.33 | 118.3 (24.23) | 392 (777) | 268 (515) | 82.9 (149.2) | Sept. 18 |
| †1,304 (267) | 9.18 | 142.0 (29.08) | 534 (993) | 333 (631) | 108.7 (195.7) | Oct. 16 |
| *1,529 (313) | 8.82 | 173.4 (35.52) | 663(1225) | 379 (714) | 118.5 (213.3) | Sept. 19 |

In the trials marked *, the initial temperature of feed water was 20° C. (68° F.); in trials † it was 13° C. (55.4° F.)

The figures in column 6 are the differences between the temperatures of feed water before entering the economiser and after leaving it.

*Thirty-six Hours' Trial.*—The duration of the above trials was sometimes four, sometimes eight hours; the results are remarkably in accord, however, as will be seen later on. It must be stated here that during a thirty-six hours' trial, November 20th and 21st, 1896, under conditions as similar as possible to those of sea service with respect to stoking, cleaning fires, sweeping tubes, &c., the results were absolutely identical with those given above.

RESULTS OF A CONTINUOUS THIRTY-SIX HOURS' TRIAL.

| Per hour and square meter (foot) of grate. | | Evaporation per unit weight of coal. | Gas temperature. | | Rise in temp. of feed water. |
|---|---|---|---|---|---|
| Steam produced. | Coal burned. | | Before entering economiser. | After leaving economiser. | |
| *Kilos.* (*Lbs.*) | *Kilos.* (*Lbs.*) | | *Degrees.* C. (F.) | *Degrees.* C. (F.) | *Degrees.* C. (F.) |
| 946.7 (193.9) | 104.9 (21.48) | 9.194 | 434 (873) | 270 (518) | 70 (126) |

During this long period of working the steaming tubes were swept only once, after 28 hours; the economisers were not swept.

*Discussion of the Results.*—In order to show the accuracy of official trials, the results were traced on a diagram (Fig. 27) in the following manner:

*Designation of the various Curves, Fig. 27.*

Evaporation per kilogram of Cardiff coal:

Scale, 10 mm. per kilogram of steam:

*A.*—With economiser. (The marks † and * have the same meaning as in previous table.)

*B.*—Without economiser. (Trials carried out by the makers.)

*C.*—Coal consumption per square meter of grate per hour.

Scale, 1 mm. for 2 kilograms.

Temperature of gases:

Scale, 1 mm. for 8 degrees C.:

*D.*—Before entering the economiser.

*E.*—After passing through the economiser.

*F.*—Rise in temperature of feed water.

Scale, 1 mm. for 8 degrees C.

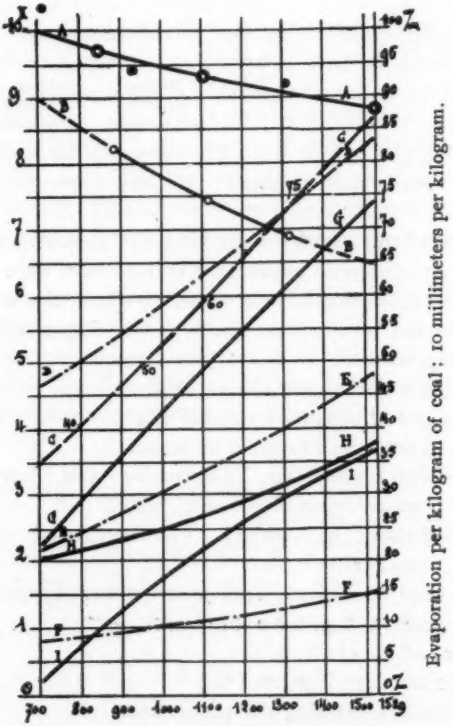
Increased efficiency of the boiler fitted with an economiser:
Scale, 2 mm. per 100:

*G.*—Increase on total efficiency $\left(\frac{A-B}{B}\right)$.

*H.*—Increase due to the rise in temperature of feed water alone.

*I.*—Increase due to better circulation.

Fig. 27.


Evaporation per kilogram of coal: 10 millimeters per kilogram.
Evaporation per square meter of grate per hour.
Scale: 1 millimeter for 16 kilograms.

FIGURES TAKEN FROM THE DIAGRAM.

| Steam per sq. meter of grate. G H (per sq. ft.) | | Steam per unit weight of coal. With economiser. A | Steam per unit weight of coal. Without economiser. B | Percentage increase on vaporization. G | Coal per sq. meter (foot) of grate. C | | Gas temperature. Before entering economiser. D | | Gas temperature. After passing through economiser. E | | Rise in temp. of feed water. F | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Kilos.* | *Lbs.* | | | | *Kilos.* | *Lbs.* | *Degrees. C.* | *F.* | *Degrees. C.* | *F.* | *Degrees. C.* | *F.* |
| .700 | 143.4 | 10.00 | 9.00 | 11.11 | 70.0 | 14.34 | 369.5 | 697 | 175 | 347 | 65 | 117 |
| .800 | 163.8 | 9.82 | 8.58 | 14.45 | 81.6 | 16.71 | 401.5 | 755 | 196 | 385 | 70 | 126 |
| .900 | 184.3 | 9.66 | 8.19 | 17.95 | 93.4 | 19.13 | 435 | 815 | 218.5 | 425 | 75 | 135 |
| 1.000 | 204.8 | 9.48 | 7.83 | 21.07 | 105.5 | 21.60 | 469.5 | 877 | 241.5 | 467 | 80.5 | 145 |
| 1.100 | 225.3 | 9.34 | 7.51 | 34.36 | 117.7 | 24.10 | 504 | 939 | 266 | 511 | 87 | 157 |
| 1.200 | 245.7 | 9.20 | 7.21 | 27.60 | 130.3 | 26.68 | 539 | 992 | 292 | 558 | 93.5 | 168 |
| 1.300 | 266.2 | 9.07 | 6.95 | 30.50 | 143.2 | 29.33 | 575 | 1067 | 318.5 | 605 | 101 | 182 |
| 1.400 | 286.7 | 8.95 | 6.71 | 33.38 | 156.4 | 32.03 | 613 | 1135 | 345 | 653 | 109.5 | 197 |
| 1.500 | 307.2 | 8.85 | 6.50 | 36.15 | 169.7 | 34.75 | 652 | 1206 | 373 | 703 | 119 | 214 |

Steam productions per kilogram of coal were taken as ordinates and total productions per square meter of grate as abscissæ. These absciscæ were selected because, steam production being precisely the object in view, it immediately characterizes the boiler power.

It may be noted that the points belonging to both series of trials are very nearly on curve *A*; therefore all these trials may be considered as in agreement.

For the sake of comparison, curve *B* was drawn, representing the average results of numerous evaporation trials previously made at the Belleville works on boilers of the ordinary type having the same diameter of tubes as the trial boiler with an economiser.

With these data, curves *G* and *H* were drawn: the ordinates of curve *G* are the values of $\frac{A-B}{B}$; the ordinates of curve *H* are the values of $\frac{h}{B}$, $h$ being the weight of steam, at the boiler pressure, containing the number of thermal units supplied to the

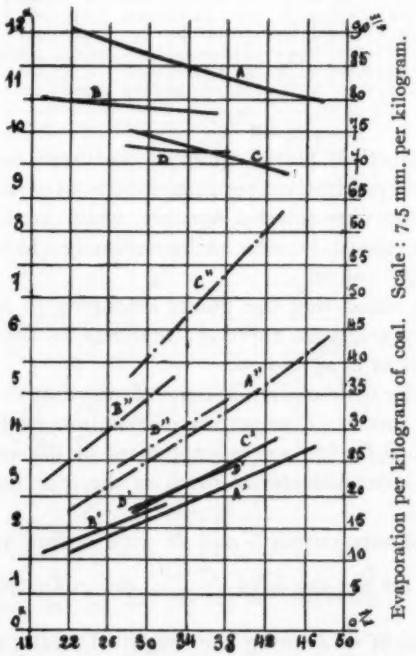
feed water by the economiser; they show, therefore, the increased efficiency due to the warming up of the feed water alone.

Finally, curve *I* was obtained by taking the differences *G—H;* it shows that part of the increased efficiency which is due to better circulation. It is, indeed, very noticeable, as it increases with more active combustion until it becomes equal to the economy produced by the warming up of the feed water.

From the fact that curve *I* rises with the rate of combustion, it may be concluded that the boiler is capable of still greater

**Fig. 28.**

Steam produced by different types of boilers per kilogram of coal, feed water being taken at 100 degrees C. and transformed into steam at 100 degrees C. (212 degrees F.).




Evaporation per square meter of grate per hour. Scale: 3 millimeters per 2 kilograms.

rates of combustion and evaporation. The trials made to the present date stop at a combustion of 175 kilogs. of coal per square meter (35.84 pounds of coal per square foot) of grate, producing 1,529 kilogs. of steam per hour, a ratio of 8.88 : 1 for steam production per unit weight of coal, and 48 kilogs. per square meter (9.83 pounds per square foot) of heating surface.

*Comparison with Cylindrical Boilers.*—It was interesting to compare the new boilers with marine cylindrical boilers. For that purpose diagrams were drawn, Fig. 28, taking as ordinates the evaporations per kilog. of coal, uniformly brought back to 212 degrees Fahrenheit (water and steam to 212 degrees), so as to provide, as far as possible, for differences in temperature of feed water and in pressures of the various boilers tested.

The abscissæ are vaporisations per square meter of heating surface, selected also with proper regard for the differences in the construction of the various types.

Evaporation trials on the boilers of the *Jean Bart*, *Suchet* and *Isly*, were made at the Indret National Marine Works. Trials of the *Hermione* were made by the British Admiralty and published by "Engineering," December 21st, 1894.

The boilers of the *Jean Bart*, *Isly* and *Hermione* are of the cylindrical return type; the boilers of the *Suchet* are of the so-called Admiralty direct type.

The diagram was completed with the coal consumptions per square meter of grate and of heating surface.

At the first glance it is seen that Belleville boilers, with an economiser, have a decidedly better efficiency than that of ordinary marine boilers, as was pointed out at the beginning of present note.

*Designation of the various curves, Fig. 28.*

Evaporation per kilogram of coal:

*A.*—Belleville boilers, with an economiser.

*B.*—*Isly* and *Jean Bart;* cylindrical return boilers, three furnaces.

*C.*—*Suchet*, same type, two furnaces.

*D.*—*Hermione*, British cruiser, same type.

Scale: 7.5 mm. per kilog.

TRIAL RESULTS FROM WHICH THE CURVES WERE DRAWN.

| | Grate surface. | | Heating surface. | | Steam. | | | Coal. | | | | Temp. of feed water. | | Steam pressure. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Per square meter (foot) of heating surface per hour. | | Per unit wt. of coal. | Per square meter (foot) of heating surface. | | Per square meter (foot) of grate surface. | | | | | |
| | *Sq. met.* | *Sq. ft.* | *Sq. met.* | *Sq. ft.* | *Kilos.* | *Lbs.* | | *Kilos.* | *Lbs.* | *Kilos.* | *Lbs.* | *Degrees. C.* | *F.* | *Atmospheres.* | *Lbs., sq. in.* |
| Belleville boilers... | 4.02 | 43.23 | 127.95 | 1,376 | 22.42 | 4.591 | 10.23 | 2.191 | .4487 | 69.65 | 14.27 | 13 | 55.4 | 15.00 | 213.3 |
| | | | | | 26.61 | 5.449 | 9.74 | 2.732 | .5595 | 86.91 | 17.80 | 20 | 68 | | |
| | | | | | 29.37 | 6.014 | 9.46 | 3.104 | .6356 | 98.69 | 20.21 | 13 | 55.4 | | |
| | | | | | 34.75 | 7.116 | 9.33 | 3.720 | .7617 | 118.30 | 24.23 | 20 | 68 | | |
| | | | | | 41.00 | 8.396 | 9.18 | 4.464 | .9140 | 142.04 | 29.09 | 13 | 55.4 | | |
| | | | | | 48.11 | 9.852 | 8.82 | 5.449 | 1.116 | 173.40 | 35.51 | 20 | 68 | | |
| *Isly*, *Jean Bart*..... | 6.85 | 73.67 | 272.53 | 2,931 | 18.95 | 3.881 | 8.92 | 2.124 | .4350 | 84.5 | 17.30 | 15 | 59 | 9.5 | 135 |
| | | | | | 32.60 | 6.676 | 8.65 | 3.770 | .7720 | 150 | 30.72 | | | | |
| | | | | | 33.10 | 6.778 | 8.78 | 3.770 | .7720 | 150 | 30.72 | | | | |
| *Suchet*..... | 4.36 | 46.89 | 190.06 | 2,044 | 28.28 | 5.792 | 8.22 | 3.441 | .7047 | 150 | 30.72 | 10 | 50 | 11.2 | 159.3 |
| | | | | | 36.24 | 7.422 | 7.90 | 4.588 | .9396 | 200 | 40.96 | | | | |
| | | | | | 42.14 | 8.630 | 7.35 | 5.735 | 1.175 | 250 | 51.20 | | | | |
| | | | | | 43.86 | 8.982 | 7.62 | 5.735 | 1.175 | 250 | 51.20 | | | | |
| *Hermione*..... | 12.83 | 138.00 | 360.00 | 3,871 | 28.08 | 5.750 | 8.02 | 3.472 | .7110 | 97.40 | 19.95 | 10 | 50 | 9 | 128 |
| | | | | | 38.14 | 7.810 | 7.85 | 4.860 | .9952 | 136.36 | 27.91 | | | | |

Coal consumption per square meter of heating surface, per hour:

*A'*.—Belleville boilers.

*B'*.—*Isly* and *Jean Bart.*

*C'*.—*Suchet.*

*D'*.—*Hermione.*

Scale: 5 mm. per kilog.

Coal consumption per square meter of grate, per hour:

*A''*.—Belleville boilers.

*B''*.—*Isly* and *Jean Bart.*

*C''*.—*Suchet.*

*D''*.—*Hermione.*

Scale: 0.5 mm. per 2 kilogs.

Following these official trials on marine boilers fitted with economisers, which demonstrated the advantages of the new type, all navies, convinced of the superiority of water-tube boilers, adopted the 1894 Belleville type.

The French navy, which had steadily employed Belleville boilers since the creation of the type with accelerated circulation (fitting them on twenty-six ships of 165,000 aggregate horsepower from 1879 to 1894), now applied the new type in the nine years from 1894 to 1903 to twenty more ships, aggregating 274,600 horsepower. The British navy, which, in 1894, had only three ships, with a total of 53,500 horsepower, fitted with Belleville boilers, nine years later possessed fifty-eight more, aggregating 912,800 horsepower. In the Russian navy, from 1886 to 1894, these boilers existed only in eight ships of 30,600 aggregate horsepower; from 1894 to 1903 they were applied to thirty-one ships having 259,000 horsepower. Other navies, which used Belleville boilers only after the 1894 type was created, applied it, until 1903, on twenty-five ships of 300,400 horsepower; and mercantile fleets, which, from 1884 to 1894, had these boilers on nine vessels only, of 50,000 horsepower, fitted them on fourteen more vessels of 57,500 aggregate horsepower.

It is beyond doubt that new installations would not have succeeded each other so rapidly had not the new type offered undeniable advantages. The official trials of three ships, carried out in 1903, the results of which are summed up in the annexed

RESULTS OF THE OFFICIAL TRIALS OF THE "SULLY," "MARSEILLAISE" AND "AMIRAL AUBE," OF THE FRENCH NAVY.

| Name of ships. | Nature of trial. | Date of trial. | I.H.P. auxiliaries included. | | Coal consumption per I.H.P. | | Coal per square meter (foot) of grate. | | Speed in knots. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | (*Engl.* | *Kilos.* | *Lbs.* | *Kilos.* | *Lbs.* | |
| *Sully* | Consumption trial at 1,800 I.H.P. | 16 June, 1903. | 2,040.4 | 2,012 | .547 | 1.223 | 48.23 | 9.877 | 9.9 |
| | Consumption trial at 14,000 I.H.P. | 10 June, 1903. | 14,166.4 | 13,970 | .668 | 1.493 | 86.962 | 17.81 | 19.5 |
| | 24-hours' trial at 10,000 I.H.P. | 27, 28 June, 1903. | 10,440.0 | 10,300 | .638 | 1.426 | 62.10 | 12.72 | 18.4 |
| | Full-power trial | 23 May, 1903. | 20,342.3 | 20,060 | .840 | 1.877 | 154.540 | 31.635 | 21.4 |
| *Marseillaise* | Consumption trial at 1,800 I.H.P. | 28 April, 1903. | 1,904.0 | 1,878 | .595 | 1.329 | 45.351 | 9.288 | 9.697 |
| | Consumption trial at 14,000 I.H.P. | 3 July, 1903. | 14,593.6 | 14,395 | .699 | 1.562 | 92.641 | 18.97 | 19.643 |
| | 24-hours' trial at 10,000 I.H.P. | 25, 26 June, 1903. | 10,658.0 | 10,510 | .654 | 1.461 | 63.922 | 13.09 | 18.5 |
| | Full-power trial | 5 August, 1903. | 21,820.0 | 21,523 | .861 | 1.923 | 168.500 | 34.51 | 21.641 |
| *Amiral Aube* | Consumption trial at 1,800 I.H.P. | 16 October, 1903. | 2,173.0 | 2,143 | .527 | 1.177 | 45.940 | 9.409 | 9.626 |
| | Consumption trial at 14,000 I.H.P | 5 Nov., 1903. | 14,319.0 | 14,122 | .530 | 1.296 | 76.0 | 15.566 | 19.34 |
| | 24-hours' trial at 10,000 I.H.P. | 12, 13 Nov., 1903. | 10,850.0 | 10,700 | .588 | 1.313 | 59.0 | 12.082 | 18.607 |
| | Full-power trial | 17 Dec., 1903. | 22,155.0 | 21,850 | .830 | 1.855 | 165.0 | 33.79 | 21.9 |

table, demonstrate these advantages, as they establish a new record for small coal consumption on large vessels of high speed.

In order to prove without discussion the superiority of the economiser type, comparative evaporation trials may also be quoted, which were carried out by order of the Minister of Marine, in 1902, under the supervision of the same committee, on three ships fitted with different systems of boilers, placed in identical conditions.

The Belleville-boilered ship selected for these trials was the *Marseillaise*, then being finished at Brest; the others were the *Jurien de la Gravière* and the *Henri IV*, both at the same stage of completion, the former at Lorient, the latter at Cherbourg.

Below are the results arrived at, on the *Marseillaise*, with three boilers having an aggregate grate surface of 11.585 square meters, 124.7 square feet.

| Date of trial. | Duration. | Coal consumption per sq. meter (foot) of grate. | | Steam pressure. | | Steam per unit wt. of raw coal. | Air pressure in stokehold. | |
|---|---|---|---|---|---|---|---|---|
| | | *Kilos.* | *Lbs.* | *Atmospheres.* | *Lbs., sq. in.* | | *mm.* | *inches.* |
| June 24, 1902..... | 6 hours | 75 | 15.36 | 19.992 | 284.4 | 10.332 | 0 | 0 |
| June 26, 1902..... | 6 hours | 110 | 22.53 | 19.157 | 272.5 | 9.392 | 2.5 | .0984 |
| June 28, 1902..... | 6 hours | 170 | 34.81 | 19.868 | 282.6 | 8.670 | 28 | 1.102 |

On the other hand, the "Parisian Association of Boiler Owners" had tests carried out under its supervision at the Belleville works in 1897 on a boiler fitted with an economiser. The results shown on the annexed table agree with those made on marine boilers.

It could be questioned, when the new type appeared, whether in actual service the economisers would not show inconveniences that might forbid their use. Experience since gained on more than 2,000 boilers provided with them enables it to be stated positively that this apparatus does not, by any means, modify the working of the boiler, which remains as safe as without economisers.

It, therefore, required only the proof that the economies of fuel stated during trials would be found also in actual service,

EFFICIENCY TRIALS MADE OCTOBER–NOVEMBER, 1897, ON A BOILER, MODEL 1896, WITH ECONOMISER.

(Under the supervision of the "Parisian Association of Boiler Owners.")

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Duration of trial, hours | 8 | 8 | 6 | 6 | 5 | 5 | 4 | 4 | 4 | 4 |
| Coal per sq. m. of grate, kilos | 69.960 | 70.375 | 98.250 | 100.080 | 125.05 | 125.150 | 147.060 | 150.125 | 175.060 | 175.125 |
| sq. ft. of grate, pounds | 14.33 | 14.41 | 20.12 | 20.5 | 25.6 | 25.63 | 30.11 | 30.74 | 35.83 | 35.86 |
| Combustion residuum, per cent | 6.87 | 7.5 | 7.84 | 8.55 | 7.44 | 7.58 | 10.18 | 7.67 | 6.57 | 5.70 |
| Nature of coal, Riddled Cardiff | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Net coal per hour, kilos | 255.165 | 255.715 | 355.310 | 357.410 | 454 23 | 454.140 | 518.250 | 545.075 | 640.725 | 646.700 |
| pounds | 562.5 | 563.7 | 783.1 | 787.9 | 1001.4 | 1001.2 | 1142.5 | 1201.8 | 1412.6 | 1425.8 |
| Evaporation per hour kilos | 2769.37 | 2959.375 | 3820.830 | 3955.830 | 4755 | 4830 | 5345 | 5581.250 | 6191.250 | 6248.75 |
| pounds | 6105 | 6524 | 8423 | 8720 | 10482 | 10650 | 11782 | 12305 | 13649 | 13775 |
| Water temperature : | | | | | | | | | | |
| (*a*) Hot well, degrees C | 13.54 | 7.62 | 12.89 | 6.92 | 12.47 | 7.26 | 12.27 | 6.58 | 12 | 7 |
| F | 56.37 | 45.72 | 55.2 | 34.46 | 54.45 | 47.97 | 54.09 | 43.84 | 54 | 44.6 |
| (*b*) After heating by exhaust steam from feed pump, degrees C | 39.32 | 40.08 | 39.47 | 34.63 | 33.50 | 37.53 | 32.15 | 35 | 33.92 | 25.84 |
| F | 102.78 | 104.1 | 103.05 | 104.33 | 92.3 | 99.55 | 89.87 | 95 | 93.06 | 78.51 |
| Gas temperature, degrees C | 217.2 | 232 | 273.47 | 285 | 331.56 | 306 | 387.69 | 389.58 | 441.15 | 404.61 |
| F | 423 | 450 | 524.25 | 545 | 628.8 | 583 | 729.84 | 733.24 | 826 | 760.3 |
| Evaporation : | | | | | | | | | | |
| (*a*) Per pound of raw coal, lbs | 9.896 | 10.513 | 9.722 | 9.881 | 9.506 | 9.648 | 9.086 | 9.294 | 8.841 | 8.920 |
| (*b*) Per lb. of net dry coal, lbs | 10.853 | 11.572 | 10.753 | 11.067 | 10.468 | 10.635 | 10.313 | 10.239 | 9.662 | 9.662 |

Heating surface, 127.85 square meters. 1376 square feet.
Steaming tubes, 85.95 square meters. 924.9 square feet.
Economiser tubes, 41.90 square meters. 451.05 square feet.
Grate surface, 4 square meters. 43.06 square feet.

in order to ensure that economisers would be accepted without objections. Letters on this subject written to Delaunay, Belleville & Co. by manufacturers who had first employed the non-economiser type and then the 1894 boiler, are the most conclusive testimonial to that effect, since industrial men care only for actual economy and remain indifferent to theoretical efficiency.

As these letters cannot be quoted here nor even extracts from them be given, because of repetitions and lack of space, a few of them only are referred to.

The manager of the Central Electric Station, Rue Trudaine, Paris (Edison Continental Co ), states that after comparative trials of a duration of four days each, he has ascertained the economy of coal due to economisers to be 21 per cent.

The firm, Pernod Fils, Viel Picard & Co., after comparative trials lasting eighteen days each, says that the benefit due to economisers is 15 per cent., and asks whether it would be possible to fit economisers on two old boilers.

Again, after comparative trials, the "Société Française d'Electro Métallurgie," states an economy of 14 per cent., and requires the boilers supplied in 1889 to be fitted with economisers.

These few examples, selected among many, are enough to fix opinion, and it would be superfluous to insist further on that point, since it is certain that similar results, namely, from 14 to 20 per cent. economy, will always be obtained when accurate comparative trials can be carried out.

The efficacy of economisers, therefore, seems to be sufficiently proved by the agreement of results above mentioned. It remains to show that their installation causes no complication liable to reduce the safety of boilers nor to render their upkeep more difficult. This will be shown by the description of this apparatus, which is now given, together with that of the boiler, with the hope of leaving in the reader's mind a distinct knowledge of the present arrangement, the one that it is most useful to remember.

### DESCRIPTION OF BELLEVILLE BOILER WITH ECONOMISER: MODEL 1896.

A Belleville boiler consists of independent parts, of light weight and small volume, easily replaced, which will be described in de-

tail as regards their construction, mode of connection and function. These are:

1. The bundle of steaming tubes.
2. The inferior feed collector.
3. The upper collector, used as a steam and feed-water purifier.
4. The downcomers and mud-boxes.
5. The automatic feed regulator.
6. The economiser.
7. The steam superheater.
8. The outside casing, made of plates and brickwork.
9. The grate with a gas mixer.

Each of the types belonging to model 1896, created to answer the various requirements of industry, viz: the marine type, the stationary type, the portable and semi-stationary types, contain all or part of the above enumerated features, but with special arrangements. It is therefore necessary to examine each type in particular.

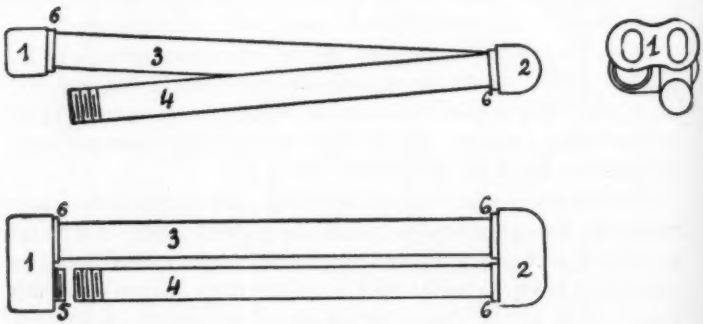



Fig. 29.

1. Front junction box.
2. Back junction box.
3. Tube without sleeve, screwed in both boxes (1 and 2).
4. Tube with sleeve, screwed on back box.
5. Short piece of tube screwed in front box.
6. Threaded rings insuring tight joints.

MARINE TYPE.

*Steaming Tubes.*—The bundle of tubes consist of a certain number of double elements, varying with the quantity of steam to be produced; each element is formed by several pairs of tubes (3 and 4, Fig. 29), both screwed into a malleable cast-iron junction box (2), called "back junction box." The threading of both parts, tube and box, is made with a slightly different pitch, the difference being only $\frac{4}{100}$ of a millimeter, but it is enough to render the screwing down of a tube very hard, with the result therefrom that the joint is absolutely tight, the more so because the threads are coated with a special soft cement which hardens when hot and fills up all intervals, thus reducing the chance of leaking; besides, a ring (6), screwed over the tube, bears tightly on the box, imprisoning in grooves cut on the faying surfaces a certain quantity of the same cement. Fig. 30 shows this coupling on a larger scale.

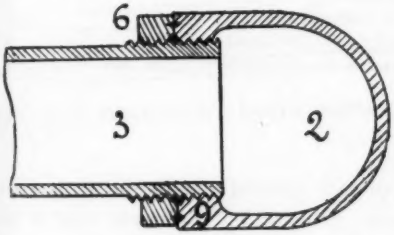



**Fig. 30.**

2. Junction box.
3. Tube.
6. Safety ring.
9. Groove cut around the threaded hole in box, to receive special cement.

The threading of boxes and rings, and the planing of their faying surfaces is made with special tools ensuring a mathematically accurate contact.

One of the tubes (3, Fig. 29), bears, at the other end, a junction box, called "front box." This tube, being purposely longer than tube (4), it can be screwed into the box, the tightness of the joint being ensured in the same manner as for back boxes.

The front box, which is to connect that tube with the lower tube (4′) of the adjoining pair (Fig. 31), is fitted with a short piece of tube (5) threaded throughout.

The length of this piece added to the length of tube (4′) gives exactly the length of tube (3); that short piece, therefore, is nothing but a part of tube (4′) cut out so as to make the connection easier, and it remains only to connect both parts, which is done through the threaded sleeve (7) covering both parts and abutting against the junction box in the same manner as an ordinary ring; an additional ring (8) secures a tighter joint.

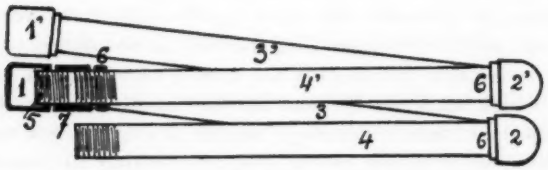



**Fig. 31.**

Two pairs of tubes consisting of
One back box (2 and 2′).
Two tubes (3 and 4, 3′ and 4′), screwed in boxes 2 and 2′.
One front box (1, 1′) screwed on the left-hand tube.
5. Short piece of tube screwed in the right side of front box.
6, 8. Safety rings.
7. Sleeve connecting the second pair of tubes to the first ones by means of piece (5).

The necessary number of such pairs of tubes is thus connected according to circumstances. (Fig. 32.) The lower tube of the lowest pair and the upper tube of the uppermost pair only bear at their free end differently shaped boxes, intended to connect the element to the feed collector on one side and to the upper steam collector on the other.

The latter box and the corresponding tube end are left-hand threaded, whilst all other threads are right hand, this condition being necessary to allow of screwing a tube at the same time into two boxes liable to turn round it, and of accurately regulating the position of the elbow-shaped box (4.)

The advantage of the above system of connection is to allow a pair, including a damaged tube, to be easily removed, and to require the cutting of only two sleeves to replace said tube.

As the lowest tubes belonging to the lowest pair are most subject to damage, both of them are connected by sleeves with the front boxes, so that only one sleeve must be cut off to remove the damaged tube.

The third and fifth boxes are provided with fusible lead plugs,

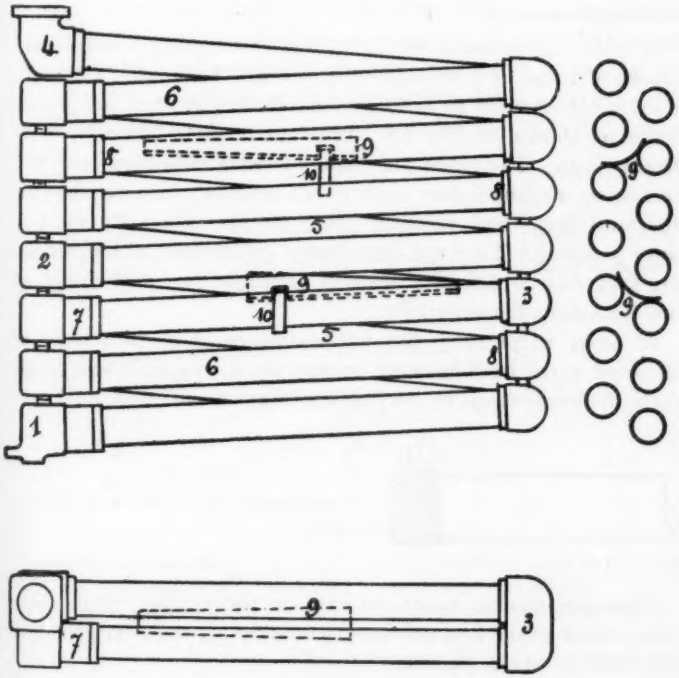



Fig. 32.

1. Lower front box connecting an element with the feed collector.
2. Front junction box.
3. Back junction box.
4. Elbow connecting element with steam collector.
5. Tubes without sleeves, on left side of element.
6. Tubes with sleeves on right side of element.
7. Connecting sleeves between tubes (6) and front boxes.
8. Safety rings.
9. Portable baffles.
10. Rings holding portable baffles.

intended to call attention in case of superheating, which would reveal an abnormal working, such as feed water getting short if fusible plugs melt simultaneously on several elements, or obstruction of an element if the plugs on that element only melt.

The appearance of an element is that of a flat coil, with constant slope. The advantages of that arrangement have been already pointed out.

In order to prevent the hot gases from going through the bundle of tubes in a straight line portable baffle plates, having holes bored in them so as to prevent accumulation of ashes, are placed as shown on Fig. 32. They are kept in place by hot-driven rings. The tubes are made of extra mild steel, and before being machined they undergo all necessary tests to measure their resistance and discover their defects, especially for the latter purpose. They are electrically galvanized, which shows any split, flaw or defective welding, through the slight coat of zinc becoming discontinuous.

In order to preserve the full resistance of tubes in way of threaded parts, both ends are pressed by a hydraulic ram to an extra thickness equal to the depth of thread. (Fig. 33.)

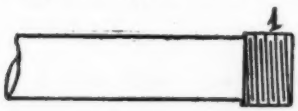


**Fig. 33.**
Strengthened end of tube with threads cut in it.

Moreover, thicker tubes are used in the vicinity of the furnace: those of the first pair are 6.5 mm. thick; the next pair is 4 mm. and all others 3.5 mm.

The junction boxes are made of malleable cast iron, capable of being forged red hot; they can therefore bear the strain of unequal tube expansion without any danger of breaking.

The cleaning holes in way of each tube are elliptical, so as to admit of self-closing plugs.

The mode of connecting tubes and boxes, just described, is beyond doubt the best obtainable, if it be admitted that joints are not intended to be undone. There can be no leakage, or at

most it can be but very slight, and should always have a tendency to disappear owing to the oxidation it provokes, unless the threading should be defective, which was the case with some boilers constructed abroad, but such a defect has never been stated concerning boilers made at the Belleville works or by licensees closely following their methods.

This mode of connection is, on the contrary, of the utmost solidity, since, without leaking, it resists the strains it has to bear through high temperature, unequal expansion of tubes, and eventually through the slight bending that is liable to take place, as in all water-tube boilers, whatever be the diameter, length, shape and type of tube connections.

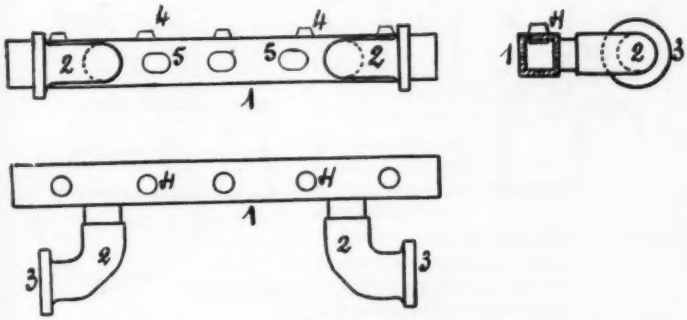



Fig. 34.

1. Feed-water collector.
2. Elbows through which feed water enters collector.
3. Connecting flange to mud box.
4. Conical feed nipples.
5. Hand holes for inspection.

*Lower Feed Collector.*—This collector (Fig. 34) is made of a square-shaped iron tube (1), very thick, with welded ends, which admits feed and circulating water from the upper collector through two elbow-shaped tubes (2), and divides it between the elements through ports of convenient size. The connection of the collector with each element is obtained by means of a conical nozzle or nipple, adjusted in a hole, having the same shape, pierced through the junction box fitted on the lowest tube.

These nipples are screwed home into the side of the iron

tube, the threaded part being slightly tapered to make a perfectly tight joint without the aid of caulking or any material.

It has already been explained that the taper on the nipple is slightly less acute than the taper in the hole it is to match, which allows of a small oscillation of the junction box if a tube is bent; thus, the contact would take place only on a line if care were not taken to fit between the two cones a very thin double sleeve of nickel or any other malleable and strong metal, which, being more deeply crushed near points of contact, compensates for the difference in angles, and secures a sufficiently wide contact surface.

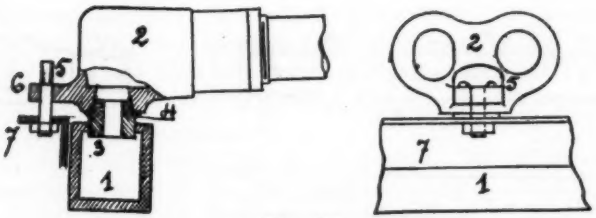



Fig. 35.

1. Feed collector.
2. Lower junction box of element.
3. Conical nipple on which the box is connected.
4. Nickel sleeve adjusted in the joint.
5. Securing bolt.
6. Projecting lug on junction box to receive anchor bolt.
7. Angle bar attached to collector.

The tightness of connection between tubes and collector is further secured by anchor bolts fastened on lugs (6), Fig. 35, and at the other end on an angle bar secured on the collector. The nuts on these bolts being always accessible under way without requiring any door to be opened, and allowing any necessary tightening, any leakage through the nipples can easily be stopped. Should it not be possible, the fault should probably be found in badly kept and rusty bolts, preventing the fastening of joints.

In way of every nipple a hand hole (5) is bored through the

collector front, in order to facilitate inside inspection and cleaning. They are closed by self-closing plugs.

The feed elbows are made of molded steel and connected with the collector by means of a short piece of tube and threaded sleeve.

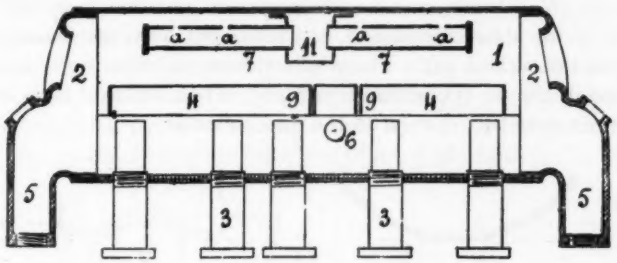
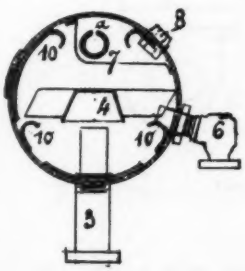



Fig. 36.




1. Upper collector or purifier.
2. Molded steel covers.
3. Steam inlet pipes.
4. Boxes over inlets of pipes (3).
5. Downcomer heads.
6. Feed injector.
7. Steam collecting pipes, bored with small holes (*a*).
8. Steam outlet.
9. Injection chamber sides.
10. Baffles.
11. Steam chamber.

*Upper Steam and Water Collector and Separator.*—This collector, Fig. 36, consists of a steel cylinder (1) closed by two molded steel ends (2), wherein the water and steam delivered by all the elements of a boiler are collected.

The successive alterations of this important feature have been already pointed out; the latest model, from a patent taken July 3d, 1899, will now be described.

The connection with elements is made through pipes (3) tightly screwed into the cylindrical shell and rising nearly to the collector axis; they bear at their lower end a flange through which they connect with the upper elbows on top of elements, Fig. 37.

Above the tops of these pipes, and over the whole space they occupy, a kind of box (4) is fitted, intended to throw downward the water and steam gushing from the elements.

The water thus thrown into the bottom of the collector meets there feed water injected through a conical nozzle placed at mid-length (6), whereby the feed is projected in a fine spray into a part of the above mentioned box separated from the remainder by two partitions (9). The whole volume of water flows down through elbows (5), which form a part of the cast-steel ends, into downcomers that carry it to the feed collector.

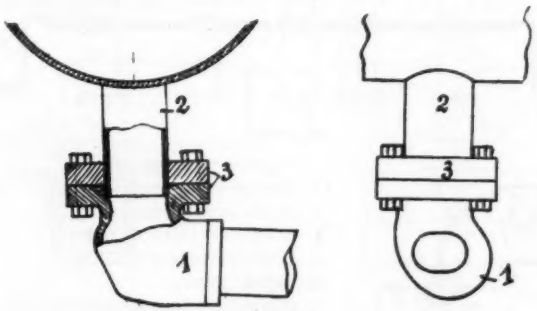



Fig. 37.

1. Elbow at top of element.
2. Steam inlet pipe.
3. Connecting flanges.

The steam coming out of the elements, after having parted from the entrained water, encounters baffles (10), on which it abandons any water particles it may still retain, and then reaches the upper part of the steam chest, where it enters two pipes (7) through small ports (*a*) having an aggregate area proportionate to the grate surface. These pipes, closed at their far end, open into a central closed chamber (11) called "steam chamber," to which they are connected by means of a strongly secured conical joint. From this chamber the steam enters the main pipe through a conical nozzle (8) screwed into the collector shell in the same manner as feed nipples into the feed collector, on which the steam valve is located.

All internal parts of the steam collector are portable, being secured by a small number of bolts easily accessible; they can be taken out for inspection or repair through doors in both covers. The box (4) which is the most cumbersome, is divided into two halves connected by bolts, which can easily be unscrewed when brought near a door, in case of need.

*Downcomers and Mud-Boxes.*—The downcomers are of steel and have a sufficient diameter to insure a free flow of circulating and feed water. There are two downcomers on each boiler, connected to the steam-chest covers by a sleeve joint, Fig. 38, similar to those used for the short tubes of element.

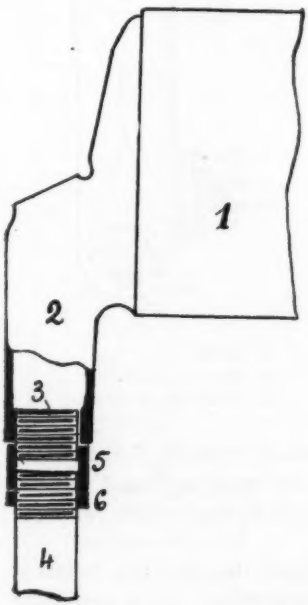



**Fig. 38.**

1. Steam drum.
2. Downcomer head.
3. Short piece of tube screwed in head (2).
4. Downcomer pipe.
5. Connecting sleeve.
6. Safety ring.

The lower end of the downcomer is screwed into a mud-box in the same manner as the steaming tubes are connected with back junction boxes.

The mud-box (1) Fig. 39, is a cast-iron or cast-steel tank, where the water is decanted before entering the feed collector, to which it is connected by a joint on the elbow secured to the latter.

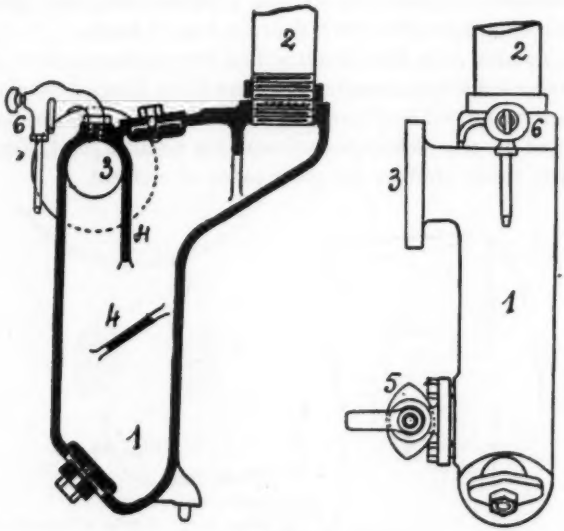



Fig. 39.

1. Mud box shell.
2. Water inlet from downcomer.
3. Water outlet to feed collector.
4. Baffles.
5. Blow-out cock.
6. Hydrometer cock.

Internal baffles, designed to conduct downward the water entering the mud-box, and upward the water leaving it, compel any material heavier than water to go to the bottom, where it remains.

A blow-out cock (5) is used to clean the mud-box before it accumulates too great an amount of impurities. These impurities are formed by the calcareous salts precipitated from feed water, when the latter is not pure condensed steam, by the lime mixed with feed water, as will be further explained, and by greasy material from the engines.

The four parts just described, namely, lower and upper collector, elements and downcomers, form the boiler itself, the other parts now to be described being only accessories intended to insure the good working of the former.

*Automatic Feed Regulator.*—The working of this apparatus is

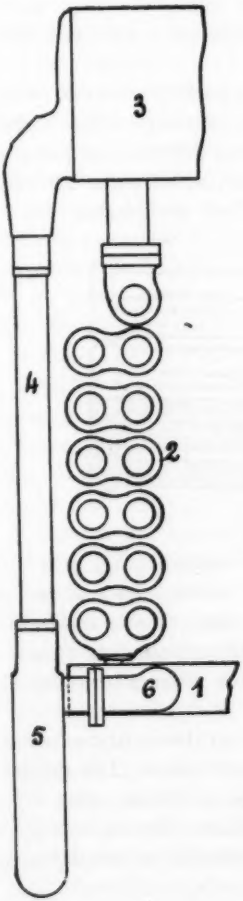



**Fig. 40.**

1. Feed collector.
2. Steaming element.
3. Steam drum.
4. Downcomer.
5. Mud box.
6. Elbow connecting mud box with feed collector.

based on the oscillations of the water level in a vessel connected with the top and bottom of the elements. That water level will be termed "apparent level," because it cannot show the real height of water in elements which, from bottom to top, are filled with alternate volumes of water and steam. It is, therefore, necessary that the variations of that apparent level should take place according to the requirements of feed, since they are to act on the regulator which maintains a suitable quantity of water in the boiler.

In any working boiler there can be no outflow of steam unless there be a drop of pressure between the surface of the boiling water and the steam delivery orifice. That difference of pressure is greater for a given amount of steam delivered when the velocity of the steam and the resistances to flow are greater.

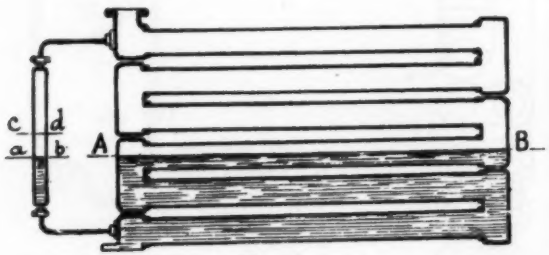



Fig. 41.

This being admitted, let us consider an element (Fig. 41) which is supposed to be fitted with water-gauge connections, and assume that steam escapes, without raising any water, from a level water surface *AB*. The resistance which the steam has to meet, although small, will react upon the water plane and cause the apparent level *ab* to rise to *cd*.

If the steam carries away liquid particles the resistance will be greater as the amount of water carried is increased. The apparent level will go up again and have no longer any connection with a real water level. It will constantly indicate the amount of resistance due to the water carried along with the steam, or, in fact, the very amount of that water.

It can therefore be understood that, if the height of the apparent level corresponding to a suitable flow of water into the steam collector has been determined once for all, a regular flow will be secured whenever this height is kept unvaried.

It then becomes easy to imagine that an automatic apparatus may be fitted on the feed pipe, such as to cause the feed to be stopped when the apparent level reaches a given point, and to be started again when it falls below that point.

If, the apparent level having its normal height, combustion becomes more active, more steam will be produced. More water being carried away, the resistance of the steam and water mixture will be increased, and the apparent level will go up. The automatic feature then coming into action so as to stop the feed, the amount of water carried away becomes less, as the bubbles of steam encounter less water on their way. The resistance will be reduced at the same time, and consequently the apparent level will go down, until feed water be admitted again. A contrary effect should take place if the combustion is retarded.

In fine, the apparent level remaining almost steady, the amount of water carried to the collector will be almost constant, and if it has been so regulated as to correspond with the maximum flow of water through the feed nipples, a maximum activity of circulation will be obtained in the boiler, whatever the rate of combustion may be.

The automatic apparatus just alluded to is the automatic feed regulator illustrated on Plate 8, which essentially consists of an automatic cock (1), the valve of which (2) is worked by a float (3) located in a box (4).

The float is an iron plate cylinder, the movement of which is transmitted through an internal lever (5) to the external lever (6) by means of spindle (7); the lever (6) works on valve (2) of the automatic cock (1).

The weight of the float and connecting parts is partially balanced by a counter weight (8) consisting of a spring (9) having a constant stretch and a series of portable, lead, weight discs, the number of which can be varied according to circumstances.

The connections are so arranged as to be in perfect equili-

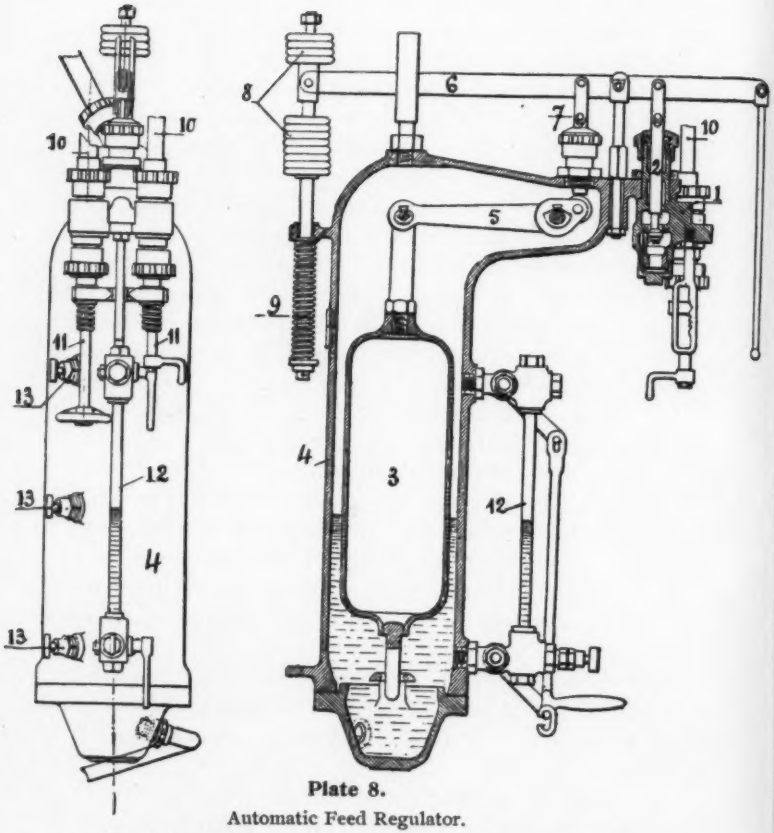



**Plate 8.**

Automatic Feed Regulator.

1. Automatic feed cock.
2. Valve and spindle of automatic cock.
3. Float.
4. Float box.
5. Float lever.
6. Balance-weight lever.
7. Spindle acting on lever 6.
8. Balance weight.
9. Balance-weight spring.
10. Feed-water inlet pipe.
11. Graduated cock rod.
12. Water-gauge glass.
13. Test cocks.

brium as regards steam and feed-water pressure; consequently the valve is in the best possible condition to feel the least movement of the float.

The number of weight discs on balance weight (8) is determined by the condition that the regulating valve must be completely closed when the height of water in the gauge glass is that fixed for a normal level. By removing a few discs, which has the same effect as increasing the weight of the float, the valve would be closed only by a higher level; that operation would result, therefore, in letting a greater quantity of water be carried into the steam collector.

Feed water, delivered by the pumps, is brought through one of the pipes (10) to one of the graduated cocks (11), each of which is connected to an independent feed collector. These cocks can be worked by hand to cut off the feed, but their principal object is to isolate the automatic regulator of a non-working boiler belonging to a group fed by the same pumps. The feed water then passes through the valve of the automatic cock, whence, through pipe 12, it goes up into the economiser, is warmed up when passing through it, and then is injected into the steam collector through a nozzle preceded by a non-return valve and a strainer provided with very fine holes to stop impurities.

Owing to its simplicity and the careful execution of all these details, this automatic feeding device, although very sensitive, is perfectly safe and positive in its working. In order to reduce to a minimum the friction of the two spindles that pass through stuffing boxes, Belleville long ago conceived a special packing, which is very smooth and which is made perfectly tight by screwing down the gland nut lightly. But, of course, this apparatus must be inspected and kept up like all machinery parts, if it is desired to preserve it in good working order.

*Economisers.*—The principle of the economiser, as applied to the Belleville boiler, has already been explained; it remains to examine the details of its construction.

All these economisers now in use consist of double elements absolutely like the steaming elements, except that the sleeve

connections have been dispensed with, the tubes being screwed at both ends into junction boxes.

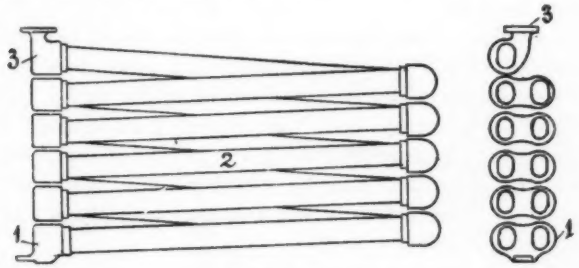



**Fig. 42.**

1. Lower front junction box, admitting water into the economiser.
2. Element formed of inclined tubes connected by junction boxes and forming a coil.
3. Water outlet.

In order to connect two pairs of tubes it is, therefore, necessary to screw tube No. 2 of the first pair deeply into the back junction box; when this tube is now screwed into the front box of the second pair it unscrews sufficiently from the back box, so that when the operation is finished only the necessary length remains in that box. As these connections are not exposed to the high temperatures of the furnace, accurate threading is enough to secure tight joints; however, safety rings are set up against the junction boxes to ensure perfectly tight connections.

Feed water is delivered into the economiser through a lower collector (Fig. 43), connected to each element by a thin pipe in former installations, or by a cone nipple similar to those used for the steaming elements.

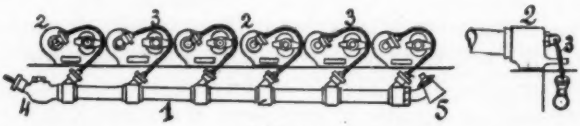



**Fig. 43.**

1. Feed-water collector.
2. Lower boxes of economiser elements.
3. Water pipes into the economiser.
4. Non-return valve box.
5. Blow-out cock.

After passing through the elements the feed water passes into an upper collector, and thence through a pipe into the feed injector.

Non-return valves are placed at the entrance of the inlet collector and close to the injector.

The ratio of heating surface of the economiser to the grate and heating surfaces of the boiler is such that it will not accidentally generate steam in case bad stoking produces an abnormal temperature in the upper combustion chamber; on the other hand, it must be considered that abnormal temperatures can take place there only for very short periods, the duration of which is never sufficient to raise the water to its boiling point, since its volume is purposely kept rather large, and since the stream of water is always cold.

Assuming, however, that steam be formed in an economiser, it will be easily understood that a large quantity would be needed to disturb the regular working of the boiler. In fact, if the feed pipe from the economiser has a sufficient area to deliver the feed water and steam together, nothing will be changed in normal working. This area is six times larger than necessary for water alone, and could be increased still further without difficulty.

There is one cirumstance, however, when steam might be generated in an economiser, namely, if engines should be suddenly stopped or slowed to low speed for a time, the fires being in full activity. If this change were to last a few minutes only, about a quarter of an hour, no evaporation should take place, but, on the contrary, the water in the economiser should get cooler, because, less steam being delivered and the combustion being slackened on account of ash-pit doors being closed, the apparent water level should go down and a considerable amount of feed water would be poured into the boiler to raise the water level to the normal height. Therefore, the water in the economiser cannot be heated to boiling point until this has taken place and it is no longer renewed; but, in order to avoid such a consequence of the feeding being stopped, a special by-pass cock has been fitted on the automatic regulator; this must always be kept open during periods of very active work, and, as

it secures a continuous feeding, even when the automatic cock is closed, the stream of cool water so produced prevents any evaporation from taking place in the economiser.

Economisers, being made up in the same manner as the steaming elements, can be inspected, kept up and repaired with the same facility.

It has been argued against economisers that they increase greatly the work of keeping up boilers fitted with them, since a greater number of element must be cleaned inside and outside. It must be remarked, however, that the steaming elements of boilers fitted with economisers have a smaller number of tubes, so that their total number is not increased in proportion to the number of elements; moreover, it has been recognised that the economiser tubes retain, through decantation, the greater part of the muddy and greasy deposits carried by the feed water, so that the steaming tubes need not be so often cleaned. Indeed, the work is but very little increased, and should constitute no real objection in face of the real advantages possessed by economisers.

Without much reason economisers have been criticised because of the facility their tubes showed toward pitting in some installations. But, if pitting took place in a few special cases, it must not be inferred from this that the fault is inherent to the system, since it would no doubt have existed in these cases, even without economisers, on the heating surfaces of any system of boilers, owing to impure feed water or other similar cause.

Cylindrical boilers were not condemned in principle when pitting occurred in them to an extent far more serious than was ever cited against economisers. A certain ship belonging to a large shipping company might be quoted, in which all the tubes of her cylindrical boilers had to be replaced after only six weeks' steaming; and there is not a person acquainted with technical naval problems who could not give similar instances.

It was not sufficient, however, to state that economisers are not worse, in that respect, than boilers without economisers; it was necessary to find some means of protecting the economiser tubes from pitting. The means adopted consists in a proper use

of lime water added to the feed. Although, as yet, the origin of pitting is not perfectly understood, it may be admitted that it is due to an acid which must be neutralized with some alkaline substance to render it harmless. The cheapest of these substances and the most easily procured being lime, it was used as soon as boiler corrosion had to be stopped, and Belleville was the first who recommended its use, as early as 1869.

When only the heating surfaces of a boiler had to be protected, lime once introduced could be used until its benefits were completely exhausted, since it could not go out; so that a small quantity added to the feed, from time to time, was enough to keep alkaline water in a boiler. But the feed water passes in a continuous stream through the economisers, and, if lime is mixed with it only at intervals, the tubes are only protected during the time when alkaline water is circulating in them. It is, therefore, necessary to mix lime continuously with the feed water in order to get a permanent effect.

For this purpose a special lime tank has been designed, giving a continuous supply. (Fig. 44.) Slaked lime introduced in that

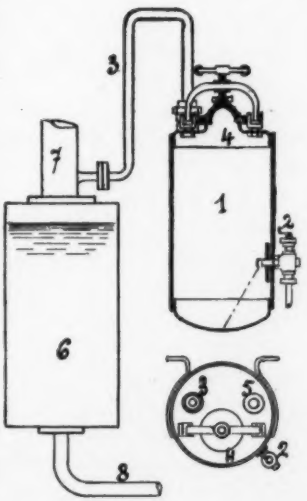



**Fig. 44.**

1. Lime tank.
2. Water inlet.
3. Water-delivery pipe.
4. Lime door.
5. Safety valve.
6. Feed-water tank.
7. Water inlet from the filters.
8. Feed-pump suction pipe.

tank, after being sifted, is diluted by a high-pressure water jet from the feed pumps, which enters the tank through a small cock, 2. The lime water thus formed goes back to the feed-pump suction through pipe 3.

Although the delivery from this tank is continuous, the amount of lime used is not much greater than it would be for any system of boiler without economiser. It is not necessary, indeed, to saturate feed water with lime, very small quantities being enough to render the feed water non-corrosive. The water in the boiler alone gets saturated, and the excess of lime is collected in the mud boxes.

Whenever regular working of this lime tank has been ensured, economisers have been free from pitting, and in certain installations where lime has been used after the discovery of existing corrosion, the fault has been stopped.

In old cylindrical boilers, where rapid corrosion was often found, a remedy has been attempted by means of zinc slabs intended to form, together with the supposedly acid water and the boiler shell, zinc-iron cells, in which the zinc alone, as a negative element, should be destroyed.

Following this more or less justified practice, zinc slabs were put in every economiser tube, but it cannot be affirmed that they were in the least efficient; in some cases it even seemed as if the use of zinc had caused pitting. Zinc, therefore, should not be advertised as a reliable means of preventing corrosion, while lime must be most strongly recommended, since its efficacy has been proved.

Moreover, experience seems to demonstrate that corrosion is less liable to take place when the stream of water passes through the tubes at a considerable velocity. Advantage has been taken of this probability in a new arrangement of economisers, in which the water passes through all the tubes successively.

This arrangement, Fig. 45, is termed "single circuit economiser," in distinction from the old one which had multiple circuits.

In order to lessen the resistance due to such an aggregate length of tubes, their diameter has been somewhat increased, to

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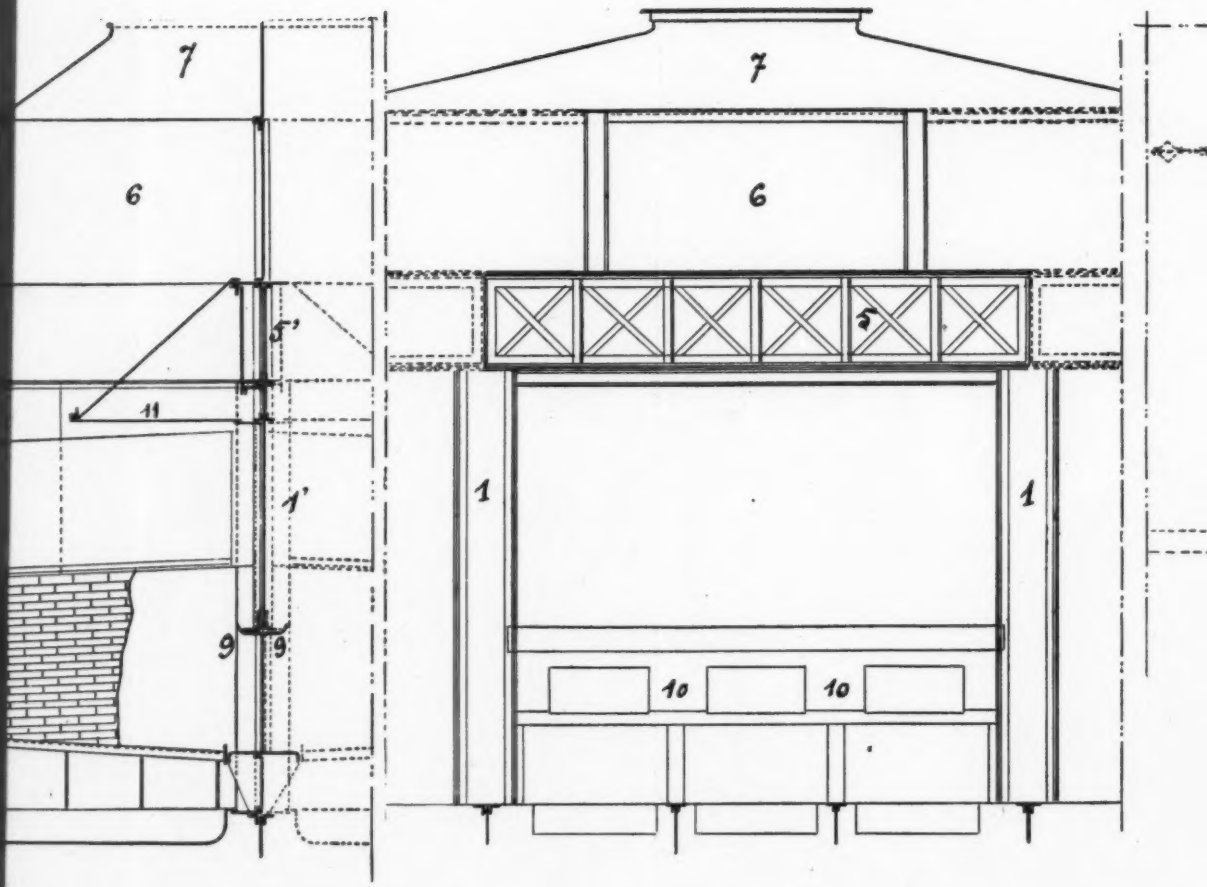
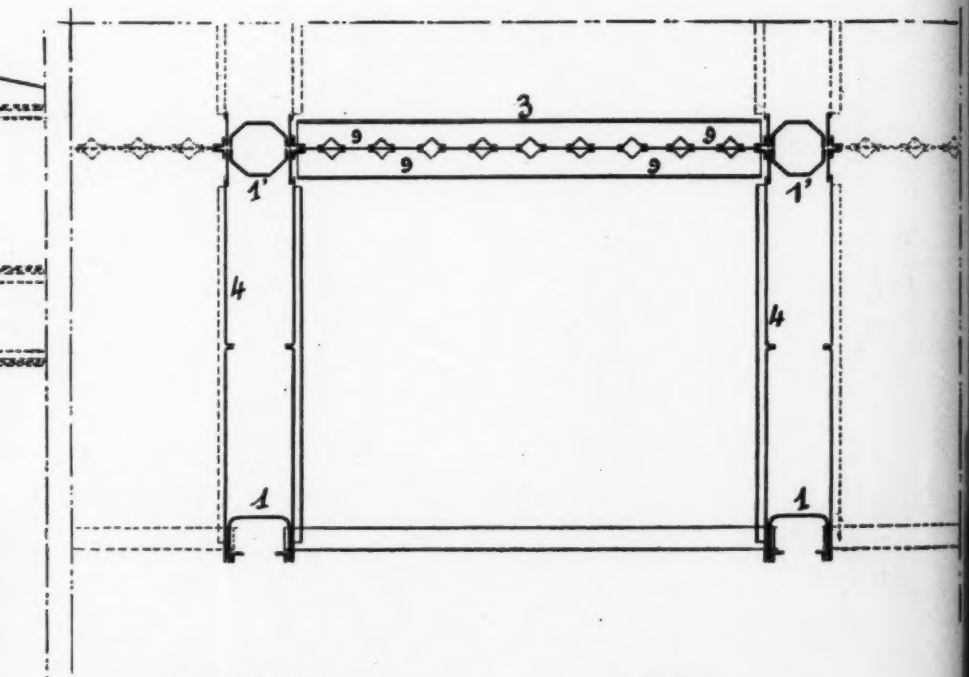
**Plate 9.**

PLATE WORK OF A MARINE BOILER, TYPE 1896, WITH E






1. Front casing pillars.
2. Back casing pillars.
3. Transverse partition between two boilers.
4. Longitudinal partition between two boilers.
5. Girder under economiser.
6. Economiser shell.
7. Uptake.
8. Furnace brick work.
9. Back tube bearer.
10. Furnace front.
11. Baffle plate on top of elements.

PLATE WORK OF A MARINE

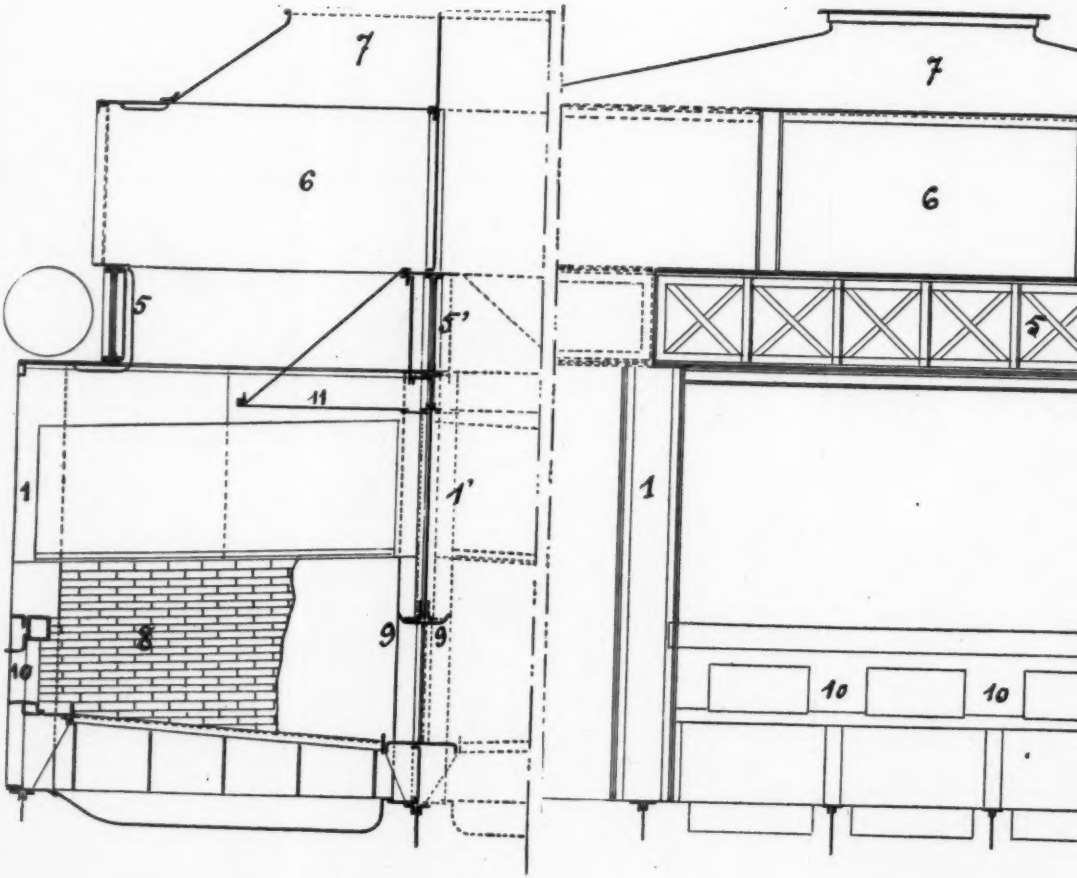
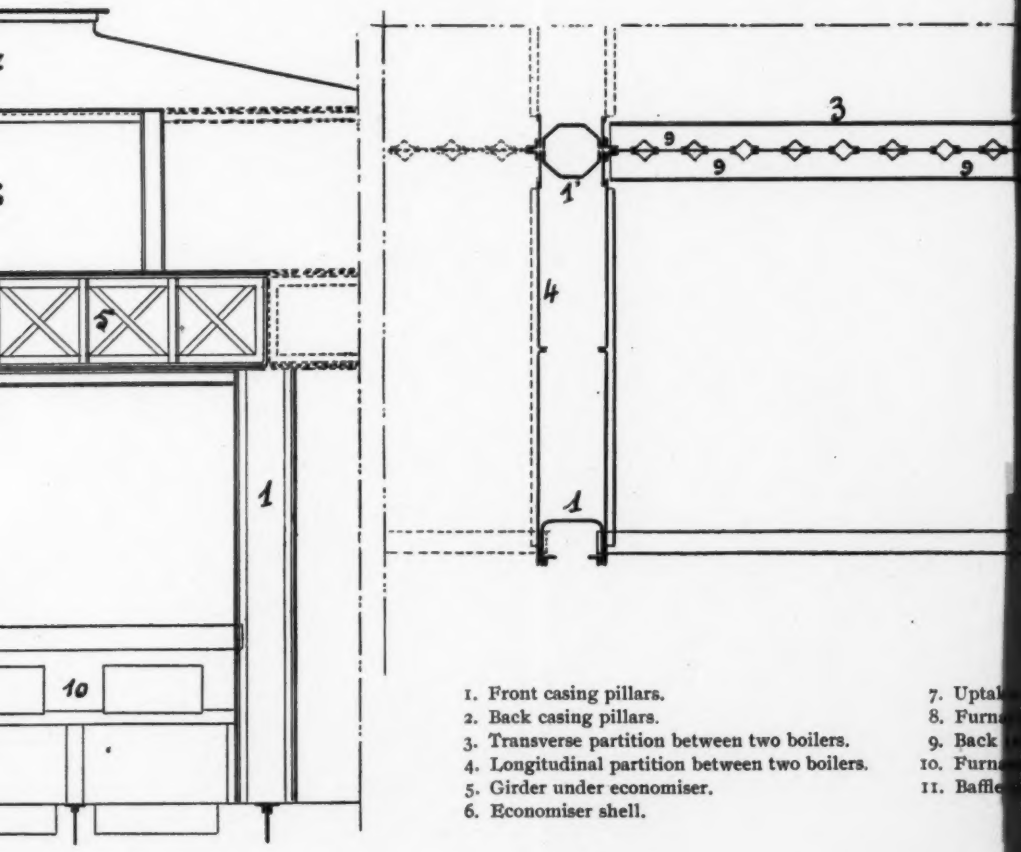


**Plate 9.**

A MARINE BOILER, TYPE 1896, WITH ECONOMISER.




1. Front casing pillars.
2. Back casing pillars.
3. Transverse partition between two boilers.
4. Longitudinal partition between two boilers.
5. Girder under economiser.
6. Economiser shell.
7. Uptak
8. Furna
9. Back
10. Furna
11. Baffle

the detriment of water velocity, which still is six times greater than that in old economisers.

*Superheaters.*—As marine boilers have not yet been provided with this apparatus, it will only be described later, in connection with stationary boilers.

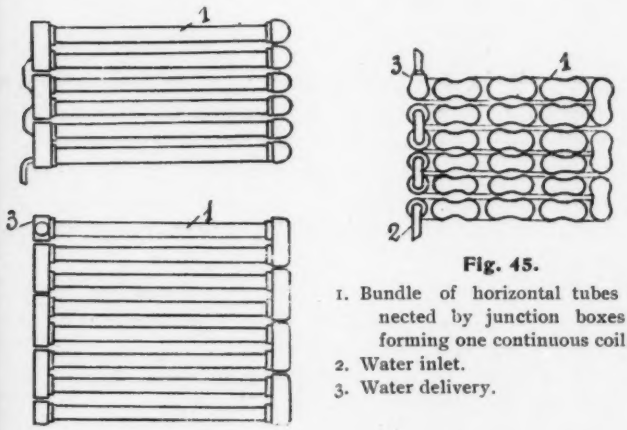



**Fig. 45.**

1. Bundle of horizontal tubes connected by junction boxes and forming one continuous coil.
2. Water inlet.
3. Water delivery.

*Plate Work.*—The whole boiler rests on four pillars of bent steel plates, which are common to two boilers in the case of several being coupled together.

These pillars, 1, 1, 2, 2, Plate 9, are connected by plate panels 3, 4, the shape of which allows of their free expansion. Pillars 1, 1, carry, at about the middle of their height, the feed collector, and on their tops the steam chest is fitted. The elements that connect these two collectors rest at back on an iron piece, 9, connecting pillars 2, 2. The downcomers are located in the concave side of pillars 1, 1.

The feed collector is further supported by plate and angle bar girders, 10, between which the furnace and ash-pit doors are secured.

Parallel to the boiler front and behind the steam chest a girder, 5, carries the front ends of economiser elements. Another girder, 5′, on top of pillars 2, carries the after ends of same elements.

A horizontal plate, D, is fitted above the steaming elements and connected with the panels surrounding the economiser elements.

The outlet for hot gases above the steaming elements is partially closed by a baffle plate, 11, which, together with the portable baffles fitted between the tubes, forces the gases to pass through the whole bundle of tubes, instead of traveling through in the shortest path.

The annexed drawing shows all parts to be well connected and so arranged as to withstand the movements caused by the most violent rolling without any undue stress or possibility of rupture. It also shows that the horizontal space occupied by the boilers is limited to that occupied by the steaming tubes and the steam chest, which means that it could not be smaller for a given heating surface.

*Grates and Gas Mixers.*—The grate bars, located below the steaming tubes, rest on the furnace fronts, which carry the dead-plate, and on plate and angle-bar girders.

The furnace sides, between the grate bars and the lower tubes, are lined with fire bricks, as shown on Plate 10.

The ash pits are formed by plate basins located between the boiler bearers.

The space between grate and tubes has been fixed after numerous experiments which ascertained the best dimensions for a maximum efficiency. It must not be thought, as has been often stated, that a larger combustion chamber increases the efficiency; this might be true with a boiler like the cylindrical one, in which the gases follow an inflected course immediately after having passed through the fuel; they are then automatically mixed more completely when the space is greater. But when the gases rise vertically, they travel in parallel streams and have no chance of being mixed unless acted upon by some mechanical means, however high the combustion chamber may be. As soon as the mixing ceases, the gases resume their vertical course, and it would be useless to increase it previous to their coming in contact with the heating surfaces.

While the combustion chamber must be just large enough to

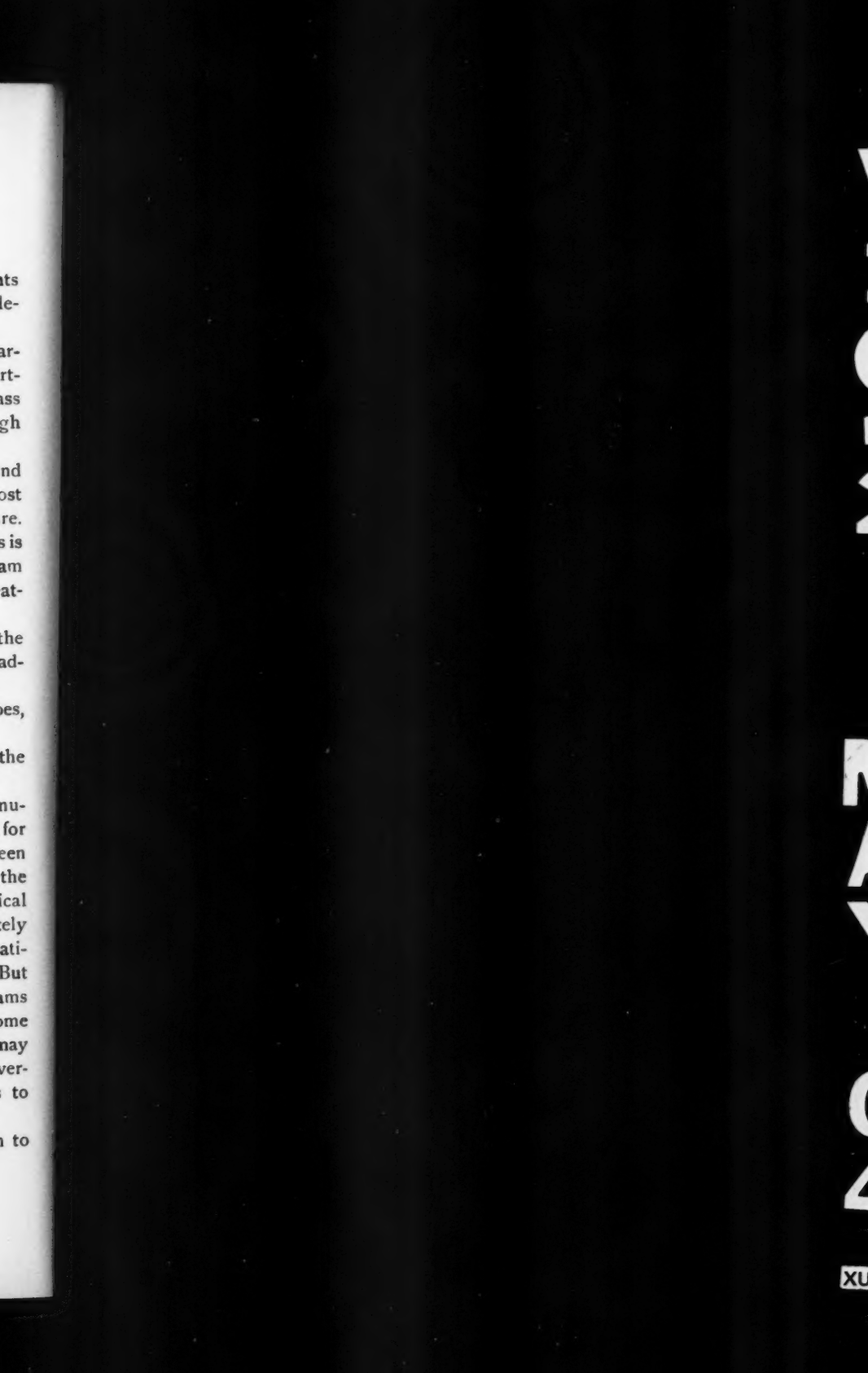
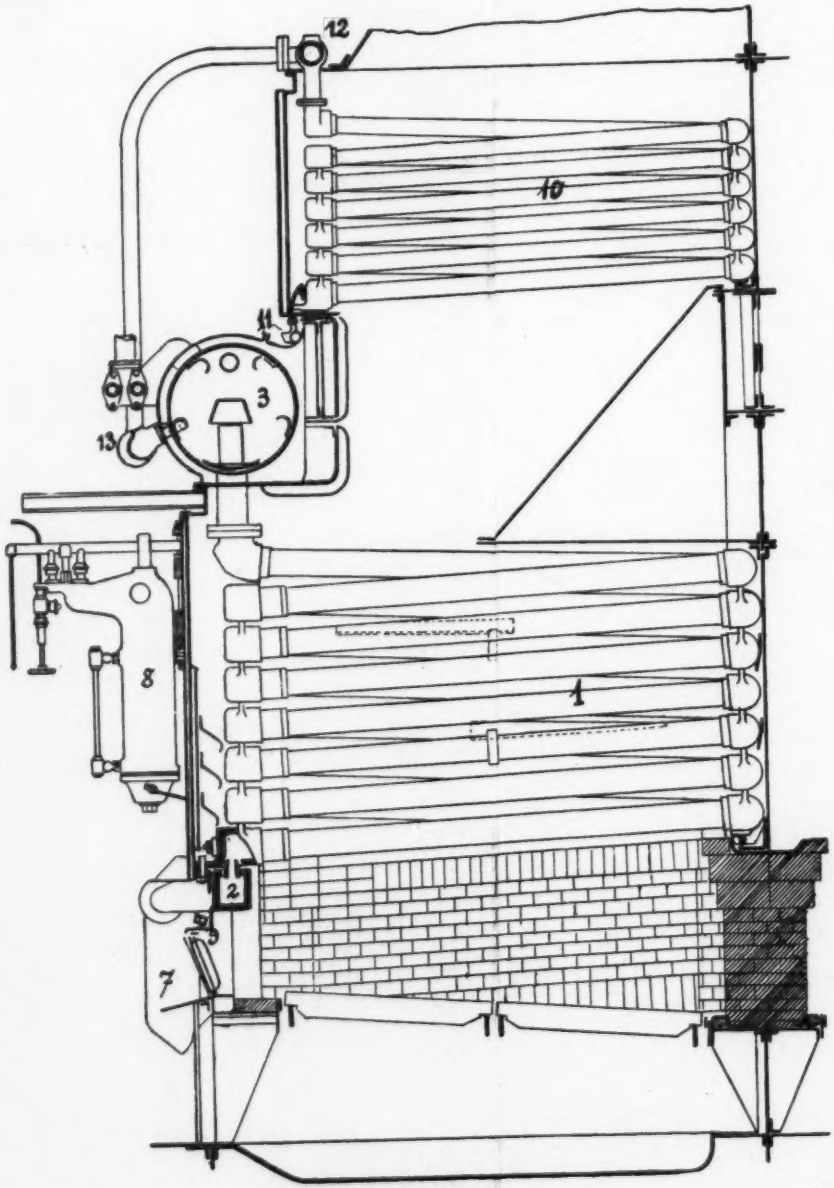
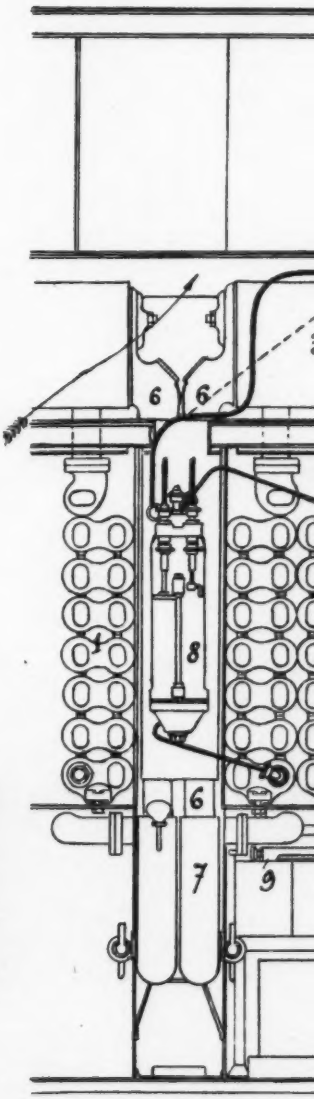


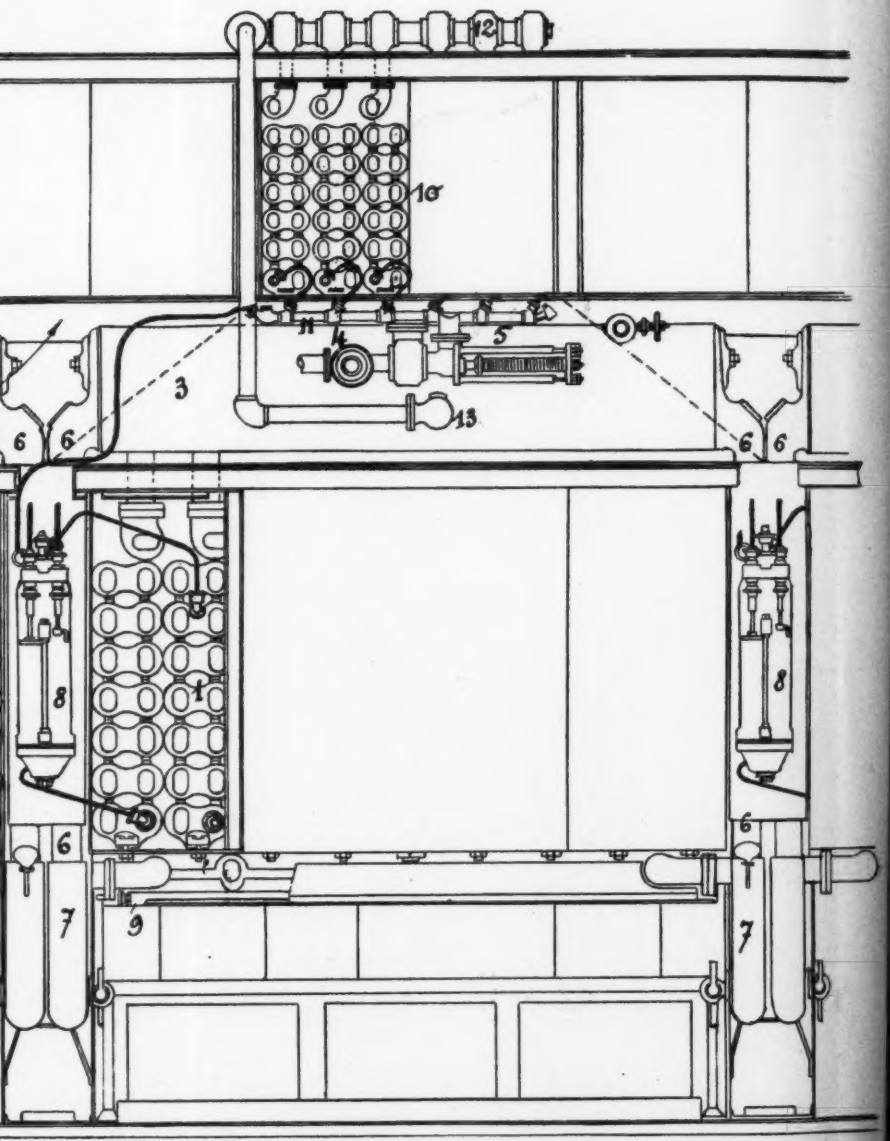
**Plate 10.**

BOILERS WITH ECONOMISERS.




1. Steaming elements.
2. Feed collector.
3. Steam and feed-water collector.
4. Steam valve.
5. Safety valve.
6. Downcomer.
7. Mud box.
8. Float box and automatic feed regula
9. Gas mixer.



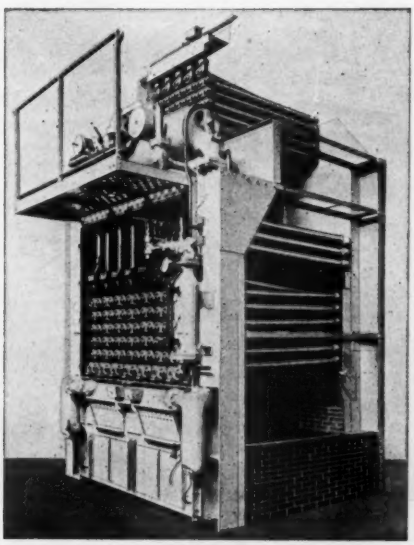

automatic feed regulator.

10. Economiser.
11. Water collector on economiser.
12. Hot water collector.
13. Feed injector with a non-return valve.

allow of a mechanical mixing of gases, it would be inconvenient to increase its dimensions beyond the necessary limit, as a large portion of the vaporization due to radiation would be lost.

Accurate experiments have indeed demonstrated that 60 per cent. of the total steam production of a boiler is due to furnace radiation, and, on the other hand, it is well known that the evaporative effect of radiation is proportionate to the square of the distance between the radiating and heating surfaces. Therefore, in systems of boilers where a better combustion is sought by increasing the height of the combustion chamber, efficiency is not improved; it is rather reduced, because the combustion is not better and the radiation is less efficient.

In Belleville boilers, the mixing of gases is effected, as previously mentioned, by means of air or steam blown in above the furnace; in marine boilers, nothing but air delivered by a compressor can be used.



Superheater.

Fig. 46.

The boiler, all parts of which have just been examined, is represented on Plate 10. The small horizontal space it occupies, in comparison with its grate surface, has been pointed out; this drawing shows that there is practically no space lost between several boilers coupled together.

### STATIONARY TYPE.

This type of boiler, intended for stationary works, has the same features as the marine type, as regards the boiler proper and the economiser; it only differs from it in regard to casings, the plate

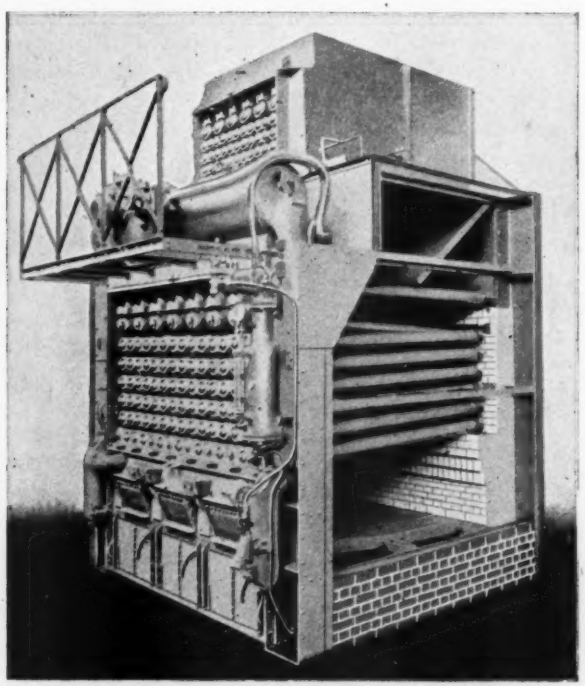



**Fig. 47.**

Stationary type boiler, model 1896.

casings being replaced by fire-brick walls, which last longer, but could not be used on board ships on account of their weight and volume.

This type is moreover fitted with a superheater, Fig. 46, consisting of tubes similar to steaming tubes, but small in number. The superheater is sometimes limited to one row of tubes and is then called a steam dryer.

Perspective views, Figs. 46 and 47, show these tubes placed in the upper combustion chamber, between boiler and economiser tubes.

The use of a superheater has no influence whatever on the efficiency of a boiler, as regards the weight of steam produced by a given weight of coal, but the steam produced contains more thermal units and the engine efficiency is thereby increased.

Experiments were carried out in March, 1901, to ascertain the amount of superheating to be obtained on a boiler working at its normal rate of combustion and at three-quarters of its normal power.

The annexed table gives the mean steam temperature registered before and after passing through a superheater in both cases:

| Hours. | At ¾ normal power. Temperatures. | | | | At normal power. Temperatures. | | | |
|---|---|---|---|---|---|---|---|---|
| | Initial. | | Final. | | Initial. | | Final. | |
| | *Degrees.* C. | F. | C. | F. | C. | F. | C. | F. |
| 8 to 9 A. M. | 191 | 376 | 224 | 435 | 190 | 374 | 249 | 480 |
| 9 to 10 A. M. | 191 | 376 | 229 | 444 | 187 | 372 | 258 | 496 |
| 10 to 11 A. M. | 192 | 378 | 229 | 444 | 190 | 373 | 250 | 482 |
| 1 to 2 P. M. | 193 | 379 | 234 | 453 | 191 | 376 | 256 | 493 |
| 2 to 3 P. M. | 192 | 378 | 237 | 459 | 191 | 376 | 267 | 513 |
| 3 to 4 P. M. | 192 | 378 | 238 | 484 | 191 | 376 | 257 | 495 |
| 4 to 5 P. M. | 194 | 381 | 235 | 455 | 190 | 374 | 261 | 502 |
| 5 to 6 P. M. | 192 | 378 | 233 | 452 | 189 | 372 | 259 | 498 |
| Mean | 192 | 378 | 232 | 450 | 191 | 376 | 257 | 495 |
| Mean superheating | 40° C., 72° F. | | | | 66° C., 119° F. | | | |

This table shows that superheating varies to some extent with the activity of vaporisation, and consequently of combustion. This system, at any rate, prevents any exaggerated superheating.

The temperature of superheated steam, thus limited, is not

absolutely steady. This could only be obtained by completing the work of individual superheaters by an independent superheater.

The adoption of individual superheaters on boilers permits the general superheater to be of limited dimensions, and the coal consumption in the latter apparatus to be greatly reduced.

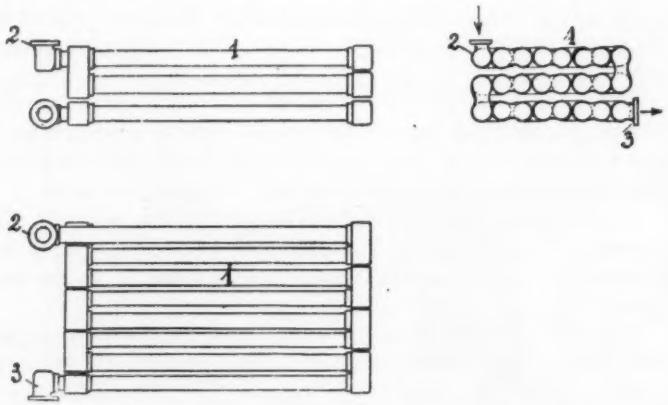



Fig. 48.

1. Element consisting of three rows of horizontal tubes forming a coil.
2. Steam inlet into superheater.
3. Steam outlet.

Independent superheaters can only be advantageous in large plants with a certain number of boilers, and especially when the system of engine used requires a high and very regular superheating; the supersheater fitted on stationary Belleville boilers answers the ordinary requirements of the industries and is no obstacle to an independent superheater being fitted in special cases, when a higher and constant temperature of steam is required.

The superheater being formed of elements consisting of tubes connected by junction boxes similar to those on steaming tubes, it can easily be cleaned inside and outside. Steam enters it from the steam drum through pipe 2 and is delivered into the main through pipe 3, Fig. 48.

The spaces available in stationary works being larger than on board ships, it has been possible to vary the location of economizers according to the requirements or conveniences of work. Figs. 49, 50, 51, 52 give an idea of these various arrangements.

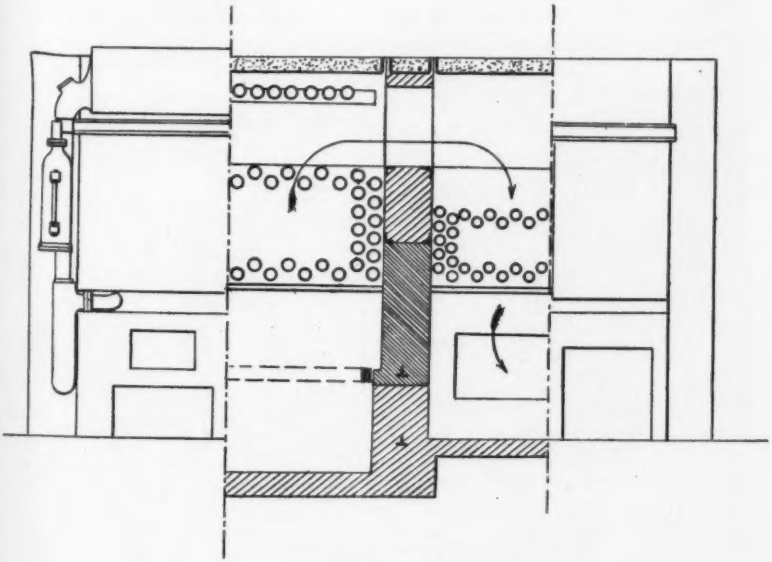


**Fig. 49.**

Belleville boiler, model 1896, with an economiser on its side.

Plate 11 shows the arrangement of eight boilers of the latest type, eight elements each; half of the sixteen boilers forming the complete plant of the Edison Electric Station, St. Denis, France.

Plate 12 illustrates the boiler plant of the Company Parisienne de l'Air Comprimé, Quai Jemmapes, Paris.

### PORTABLE TYPE.

This type is intended for easy and economical transportation. It enables small works to be provided with comparatively large powers in small spaces, even on upper floors of inhabited houses.

Where there are no roads, as in mountainous districts, these portable boilers can be divided into light sections that can be carried by mules.

The details of construction of portable boilers have been simplified to the greatest possible extent in order to spare weight. Their efficiency is less than that of stationary Belleville boilers. Portable boilers consist of single elements of tubes 82 or 100 milli-

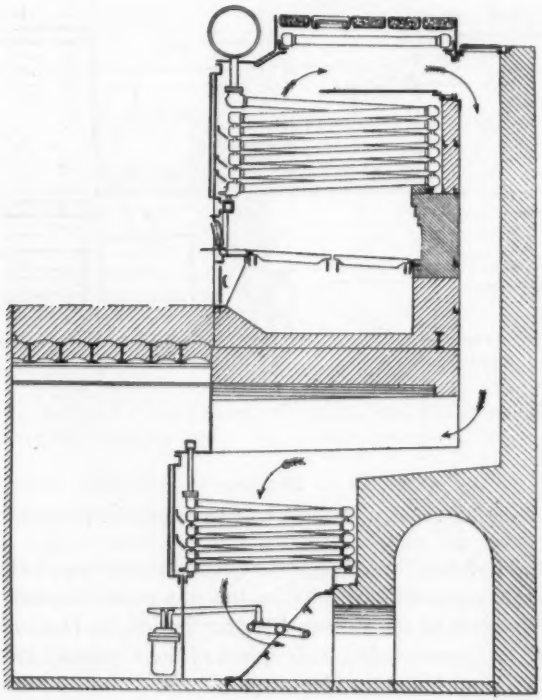


**Fig. 50.**

Belleville boiler, model 1896, with an economiser placed underneath. Arrangement adopted for the Edison Continental Co.'s Electric Stations, Avenue Trudaine and Rue Drouot, Paris.

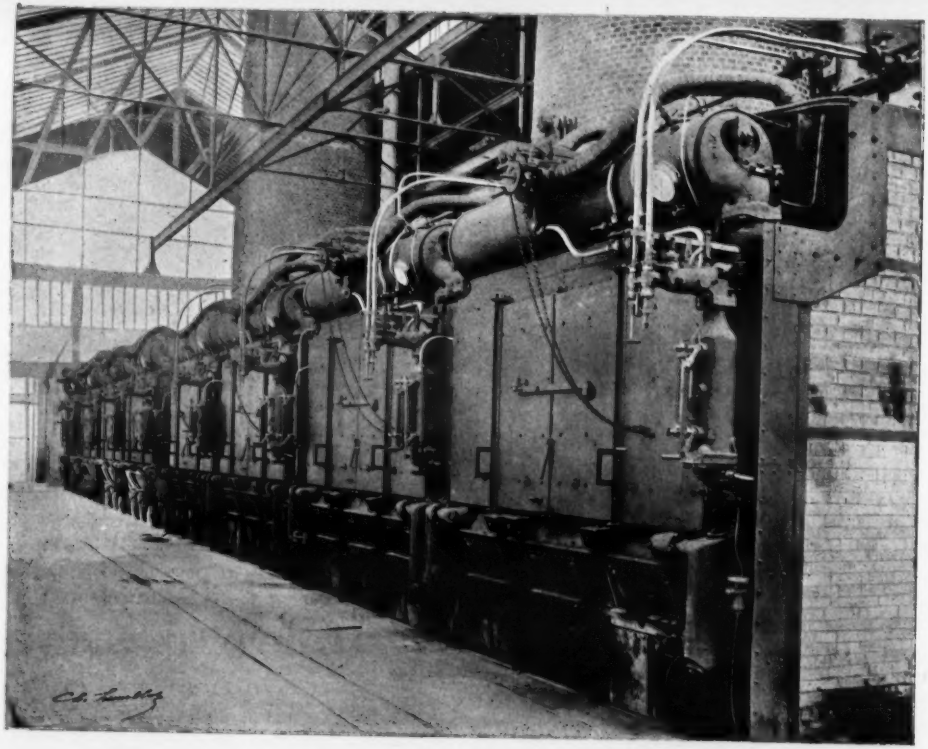


**Plate 11.**

EDISON ELECTRIC STATION SAINT-DENIS.

**This installation consists of 16 boilers; aggregate production of 56,000 kilograms of steam per hour.**

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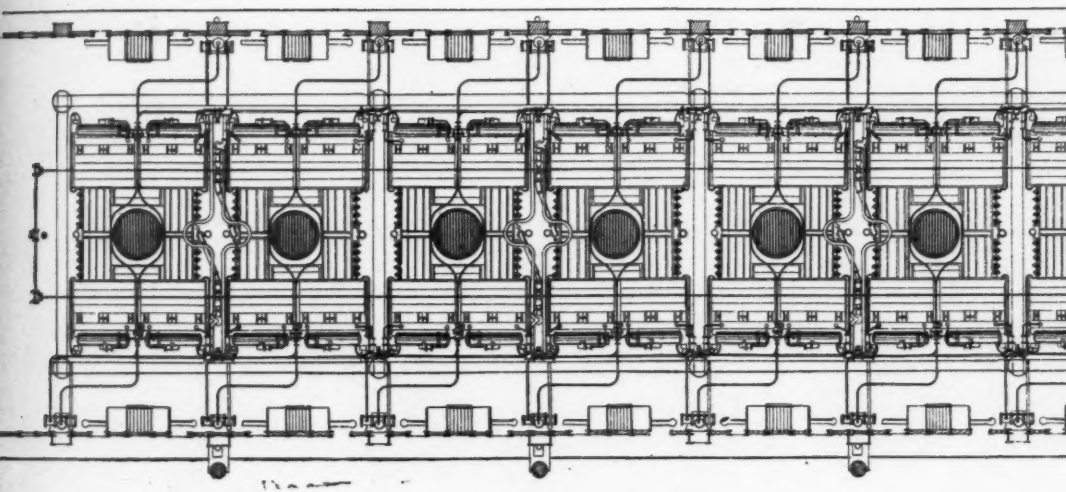
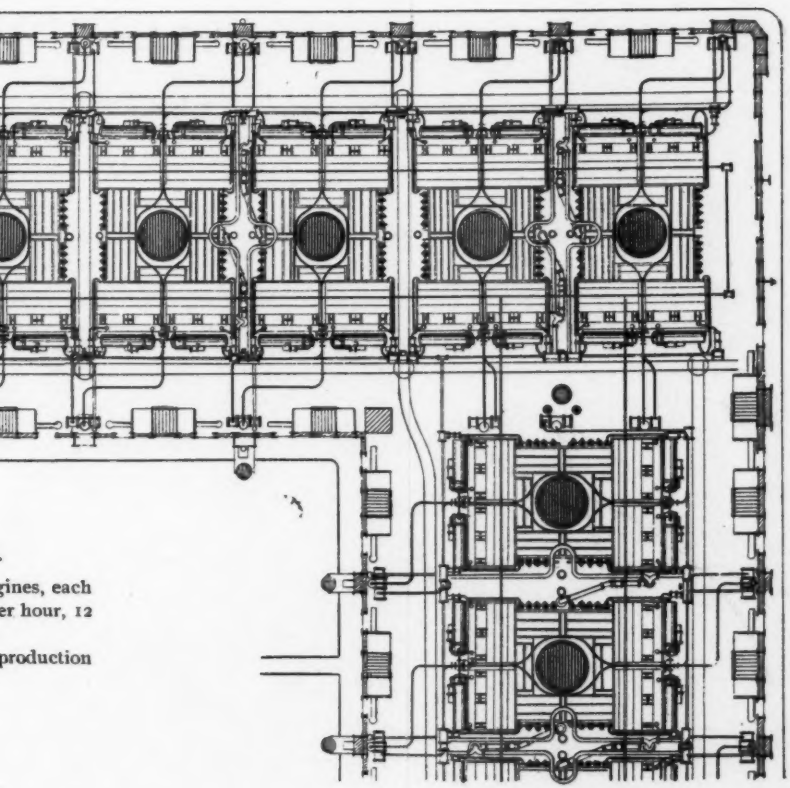


**Plate 12.**

HALF PLAN OF THE ELECTRIC WORKS, QUAI JEMMAPES, PARIS.

The works on Quai Jemmapes include now (September, 1903), eight 1,000-H.P. engines, each taking steam from a set of four Belleville boilers, with economisers; steam production per hour, 12 tons. In normal service, three boilers supply sufficient steam to one engine.

The complete plant will include twenty-three similar power units. The total steam production per hour will be 276 tons.



gines, each
er hour, 12

production

meters external diameter. The whole casing is made of plates and angle bars. The normal production of these boilers, at natural draft, is from 100 to 800 kilograms of dry steam per hour. Under 400 kilograms production they can be shipped complete and ready for work.

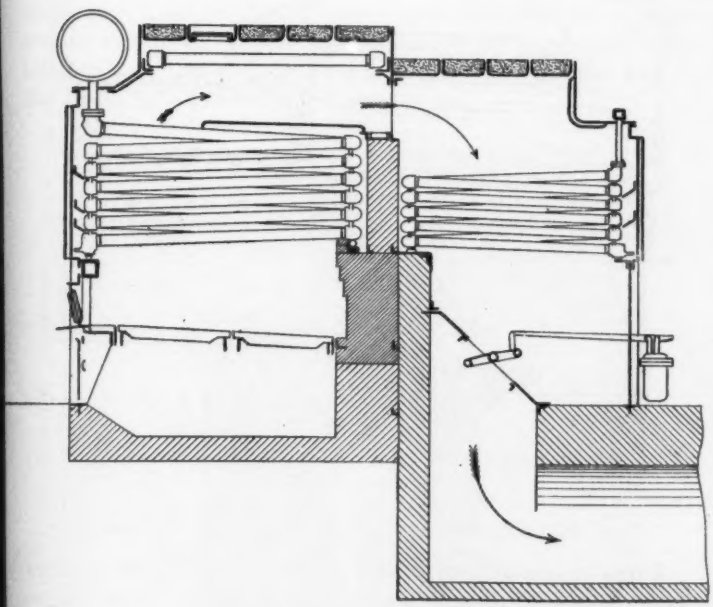


**Fig. 51.**

Belleville boiler, model 1896, with an economiser at the back. First arrangement.

When the available height is sufficient, or weight does not interfere with the arrangement, portable boilers can be fitted with two more rows of tubes and a draft register. The cost is not greatly increased thereby, and the efficiency is then not far from that of stationary boilers without economisers.

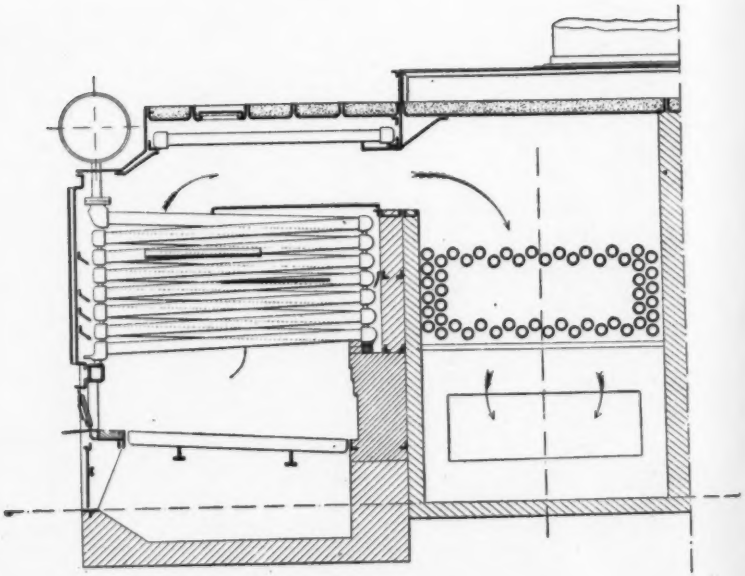


**Fig. 52.**

Belleville boiler, model 1896, with an economiser at the back. Second arrangement.

SEMI-STATIONARY OR LOCOMOBILE TYPE—(TYPE DEMI-FIXE.)

These apparatus, Fig. 53, are simple and strong locomobiles. They consist of a portable-type boiler with a vertical engine secured at the back on the outside casing.

This series of types includes four models of 5, 8, 12 and 16 effective horsepower (brake horsepower). All parts are easily accessible for oiling and keeping up under way. The shaft and connecting-rod bearings are ample, so as to ensure durability. Steam is exhausted into the stack to produce a strong draft.

The boilers are constructed for a larger steam production than required by the engine. They are automatically fed by the feed regulator and a single-effect plunger pump worked by the engine.

This type offers the same advantages as portable boilers; they are light, steam is rapidly got up, and they are perfectly safe. Such machines are very handy for small workshops, even on upper floors not specially braced for heavier installations. They can be worked by inexperienced firemen, and in the mines on the gold coast of Africa, some of these machines, worked by natives, have given very good results since they were put into operation in 1882. The same may be said of the locomobiles supplied to the "Croix-Vallon" estate in Madagascar, 1898, and to the Dutch government in Java, etc.

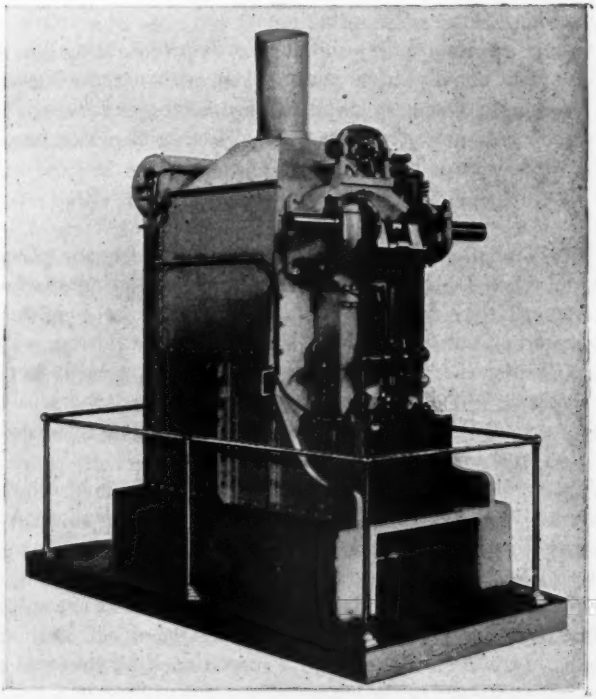


**Fig. 53.**
BELLEVILLE LOCOMOBILE.
4 sizes; 5, 8, 12, 16 H.P.

The most varied industries, especially agricultural plants, are using Belleville locomobiles, which, owing to their light weight, are fitted for frequent removals. The apparatus can be mounted on wheels, and, for use at any fixed spot, needs only to be wedged with the jacks with which they are provided.

When they are to be carried through mountains having no roads fit for wagons, the 5 and 8-horsepower locomobiles can be divided into parts not exceeding the normal load of a mule or a few men. The casings are bolted, not riveted, and can be carried separately, as well as the elements, steam drum, grate bars, etc. The engine frame also can be divided, as well as the wheels and the fly wheel, into easily portable parts.

These machines are very suitable for electric lighting; for that purpose it is convenient to supply them with a reducing valve and another fly-wheel, in order to ensure more steady working. They are easily mounted on a pair of low brick walls, between which the ash pit is located.

### LAUNCH BOILERS.

Belleville boilers constructed for navy launches or pleasure boats may be considered as a special type, answering special requirements; they are distinguished by their light weight, high steam production, safe working and rapid steam raising. These boilers consist of single-tube elements. They are easily kept up and repaired, which latter contingency seldom arises.

Over 400 Belleville boilers have been supplied to boats and launches in the French Navy.

*Working With Sea Water.*—If necessary these launch boilers can be worked with sea water, under the condition of maintaining in them a pressure of over 10 atmospheres (142 pounds per square inch). The corresponding temperature, 183 degrees centigrade (380 degrees Fahrenheit), is necessary to precipitate the sulphate of lime from the water heated in the steam drum, and continuous blowing out is required through a special cock on the mud box. The heat contained in the blown-off water is utilized in a coil surrounding the feed pipe, so that the loss of heat is reduced to a mimimum.

The draft can be stimulated by exhausting steam into the funnel. In this case special arrangements are provided in order to have a silent exhaust.

*Power.*—The two ordinary types of launches used by the French Navy have 16 and 28-I.H.P. engines. The corresponding boilers have 21 and 36 square decimeters (2.26 to 3.87 square feet) of grate surface, respectively, or 1.3 square decimeter (.14 square foot) per I.H.P. They amply supply the necessary steam.

### GENERAL REMARKS.

Any impartial critic having followed the long sequence of improvements made upon the original 1859 boiler will acknowledge that the present 1896 type no longer retains any of the defects which were found in former installations.

Easy cleaning of heating surfaces, regular feeding, induced water circulation, improved efficiency, each of these features in its turn marked a new step forward and gradually brought the Belleville boiler to its present capability of fulfilling all industrial requirements.

The numerous installations carried out and the remarkable results attained in point of both duration and efficiency should put its qualities above discussion, had it not to meet the attacks of competition. Its success excited envy, and, after showing the way to all boiler inventors, it was accused of imperfectly fulfilling those very conditions which it had demonstrated to be required from a good boiler from whatever maker.

Criticism then ran wild, and succeeded in some instances in raising suspicion against the Belleville boiler, against which other boilers were opposed, and for these opposed boilers their advocates thought to show their value merely by trying to prove that they possessed equivalent qualities and gave equal results.

Each of the systems advertised during the last few years, after the last difficulties connected with the creation of a water-tube boiler had been overcome by the Belleville type, boasts of having to a larger extent some of the essential qualities that distinguish this boiler, but which it alone summarizes.

One boasts an active water circulation ; another, a more or less

advantageous arrangement of the combustion chamber; another, of repairing facilities; still another, of burning without difficulty useless quantities of coal; but no system has proved to have a better efficiency under practical limits of combustion, to be more easily worked and kept up, less liable to breakdowns nor of a greater durability than the Belleville boiler.

Such interested criticism might therefore be left aside, after having supplied the reader with means of refuting it; but it is necessary to answer the criticisms formulated by the Water-tube Boiler Committee, appointed by the British Admiralty, in accordance with a Parliamentary vote, to examine certain questions referring to modern marine boilers. Not that this criticism has a greater value than that raised by competition for the sake of private interests, but two other reasons make it a duty to refute it; first, the world-wide publicity given to it, and second, the authority apparently attached to the couclusions of such a committee, whose report should be expected to be conscientiously drawn up.

First of all, it is a remarkable fact that, of this committee, entrusted with studying questions relating to modern boilers, one member only had handled water-tube boilers; they could not, therefore, give an opinion on such boilers except as they based it on the information they gathered concerning Belleville boilers, this being the only system of water-tube boilers then in use in the British Navy, together with older cylindrical boilers. While they could compare these two types, they were practically unable to ascertain the value of other water-tube boilers and they had no ground to suppose that some defects of the Belleville boilers, which were pointed out to them and which will be further examined, would not exist and be even more serious in other systems.

But this Committee's first conclusion was "that the advantages of water-tube boilers for naval purposes are so great that provided a satisfactory type of water-tube boiler be adopted it will be more suitable for use in H. M. Navy than the cylindrical boiler."

Since the advantages of water-tube boilers could have been

made clear to them only by the Belleville system, the committee thus admits that they are better than cylindrical boilers. If it be remembered that the Belleville boiler was already reputed an excellent one, it could not be more highly praised.

It is, then, rather strange, after such a statement, that the Committee admitted, in paragraph 3 of its report, that Belleville boilers were to be withdrawn in favor of one among the four types they recommend, if any of them should be recognized later as being the best.

It is true that this opinion was not shared by the only competent member of the Committee, who added the following statement to the report:

"I concur with the above report, except as regards paragraph 3, and on the point dealt with in that paragraph my report is as follows:—

"(1) Although the Belleville boiler has certain undesirable features, I am satisfied from considerable personal experience and from the evidence of engineer officers who have had charge of boilers of this type in commissioned ships, that it is a good steam generator, which will give satisfactory results when it is kept in good order and worked with the required care and skill.

"I am also satisfied from my inspection of the boilers of the Messageries Maritimes Company's S.S. *Laos*, after the vessel had been employed on regular mail service between Marseilles and Yokohama for more than three years without having been once laid up for repairs, that, with proper precaution, the excessive corrosive decay of the tubes which has occurred in some instances can be effectually guarded against.

"(2) Having in view the extent to which Belleville boilers have already been adopted for His Majesty's ships, and the fact there are now three or four other types of water-tube boilers which promise at least equally good results, I am of opinion that, pending the issue of the final report of the Committee, Belleville boilers should not be included in future designs. At the same time, I see no necessity for delaying the progress of ships which have been designed for Belleville boilers in order to substitute another type of boiler."

The Committee, wishing to justify its opinion, enumerates in its reports "the points in relation to the construction and working of the Belleville boiler considered to constitute practical objections of a serious nature."

These points must be dealt with in detail, because they sum up all that could be imagined by the most violent criticism against the accused boiler; the exact terms of the report are hereafter quoted:

"(*a*) The circulation of water is defective and uncertain, because of the resistance offered by the great length of tube between the feed and steam collectors, the friction of the junction boxes, and the small holes in the nipples between the feed collector and the generator tubes, which also are liable to be obstructed, and may thus become a source of danger."

If the Belleville boiler had not passed through the stage of long and successful practical application, the above expressed fear might be explained by theoretical conceptions easily refuted by reasoning and calculations. But this boiler is by far the earliest type of all water-tube boilers, and innumerable specimens of it have been in actual service, on land and at sea, during a great many years, and have given practical and satisfactory results; this certainly would not have been the case, had not the circulation been certain and regular.

As a philosopher proved motion to exist by walking, so the Belleville boiler proves circulation to take place in it by the very fact of its good working. This is an experimental proof that no reasoning whatever can refute.

As to the small holes in nipples between the feed collector and the generator tubes, they secure a continuous water flow and, consequently, an equal distribution of feed and circulating water between all the elements. Their diameter, exceeding 40 mm. (1.6 inches) in boilers of moderate power, is far greater than the inside tube diameter of torpedo-boat boilers, which are now recommended for large ships; it is also much greater than the annular water space available for circulation in concentric tube boilers. It is, therefore, hardly to be understood that the danger of an obstruction can be greater in the Belleville type than in others.

"(*b*) The necessity of an automatic feeding apparatus of a delicate and complicated kind."

If it is desired not to throw away the capital advantage of having a small volume of water in water-tube boilers, it is necessary to use an apparatus capable of ensuring automatically a regular feed in proportion with the steam consumption. This result will never be obtained by regulating the feed by hand, the necessary amount of feed water varying continuously on account of maneuvers or of the unavoidable differences in the steam production of the units forming the boiler plant of a large ship.

Since the Committee formulated the above objection many types of boilers which then had no automatic feed regulators, and which were recommended by the Committee, have been fitted with such apparatus, and their makers have advertised this addition as an improvement to their system.

An automatic feed apparatus being needed, the Belleville boiler, less than any other, deserves the reproach of being too delicate and complicated, and the committee should have pointed out where delicacy and complication lie, so as to offer opportunity to examine whether other systems are stronger and simpler.

The truth is that, where the automatic regulator is well made, when the spindle packings are well kept and the water pressure sufficient, which conditions are always fulfilled in feed apparatus constructed by the Belleville works, it is a perfectly reliable instrument, and to such an extent that on the "Messageries Maritimes" mail steamers, despite precise instructions issued by the makers, complete journeys have often been accomplished without using the water gauges, the men trusting the automatic regulators, the working of which they only checked from time to time by moving the lever rod. This practice, which, of course, ought not to be recommended, never caused any accident.

"(*c*) The great excess of the pressure required in the feed pipes and pumps over the boiler pressure."

This requirement, due to the necessity of ensuring a regular feed in all the boilers, notwithstanding the unavoidable differences of pressure between the several units, cannot be objected to, unless the makers be unable to ensure the tightness of pipes and

joints at a pressure a few atmospheres in excess of that commonly employed. It is true that some English makers showed themselves most neglectful in that respect.

"(*d*) The considerable necessary excess of boiler pressure over the working pressure at the engines."

Over pressure is advantageous for the sake of the working of the engines, whatever be the boiler system. If advantage of it had never been taken with the only boiler system the members of the Committee knew, namely the cylindrical type, the reason must be found in the fact that these boilers hardly stood the required engine-working pressure. With water-tube boilers, which can stand the highest pressure without difficulty, overpressure has been generally adopted, although it is not compulsory, and has led only to fitting tighter pipes and joints, which has not been found difficult, at least in the French Navy where it is the general custom.

"(*e*) The water gauges not indicating with certainty the amount of water in the boiler. This has led to serious accidents."

It has been understood that the water level of Belleville boilers is nothing but an apparent level intended to show that a mixture of water and steam is traveling from the bottom to the top of the elements, the proportion of water being larger when the level is high. It therefore gives a very accurate indication of the volume of water contained in a boiler, not up to a certain height, but in the whole boiler. The Committee seems to have been unaware of this particular circumstance. As to the serious accidents alluded to, assuming that they took place and that the uncertain indications of the water gauges caused them, these gauges must have been badly kept up or choked, and, if such is the case, any system of boilers, without exception, is liable to the same criticism.

"(*f*) The quantity of water which the boiler contains at different rates of combustion varying, although the same level may be shown on the water gauges."

The mere fact of expressing this objection shows that it was formulated by persons wholly ignorant of the working of a Belle-

ville boiler. Its ability to regulate the volume of water automatically according to the rate of combustion, so that the amount of water carried along by the circulation shall always be the same, is the most striking feature that can be advocated in favor of it; it ensures the production of dry steam at any working rate, allows of sudden variations of the engine speed, causes an abundant feeding to take place when the engines are suddenly stopped, by which the pressure is kept to a certain extent below the safety-valve load, and finally stops the feed temporarily in case of a rapid increase of speed, so that the whole activity of combustion is devoted to producing steam and preventing the pressure from falling. If the watchfulness of stokers had to be depended upon, however well trained they may be, great working irregularities and great differences in the condition of the steam delivered to the engines, should no doubt be expected.

"(*g*) The necessity of providing separators with automatic blow-out valves on the main steam pipes to provide for water thrown out of the boilers when speed is suddenly increased."

The Belleville boiler, having no stagnant water in its steam chest, is less liable than any other to priming, and far less than the cylindrical boiler, so well known to the members of the Committee. It is therefore manifestly unjust to reproach it with a feature intended to avoid the consequences of a defective regulation of water levels, or of an abnormal steam condensation in the pipes, and which all systems of boilers can usefully employ. This criticism will hardly be understood when it is pointed out that the general separator permits the water circulation to be augmented in the case of a leaky condenser mixing salt water with the feed, so as to prevent the formation of salt deposits on account of the circulation being more active, a little water can then be carried away by the steam without affecting the working of engines.

"(*h*) The constant trouble and loss of water resulting from the nickel sleeve joints connecting the elements to the feed collectors."

This defect is of the same nature as those attributed to over pressure in feed pipes and in the boilers, inasmuch as they have

never been stated anywhere, except in England. Some members of the Committee formed a delegation to Marseilles, in order to inquire into the working of the Belleville boilers on board the mail steamers *Laos* and *Indus*. The inspector of machinery, who joined the delegation, even sailed for Japan on board the *Indus;* but they never could find any trouble with leakage through the nipples. In the French Navy neither loss of water nor troubles of any kind have been reported.

It must then be admitted either that the nipples were defective in the cases pointed out by the Committee, or that some neglect in keeping up the boilers had made it impossible to screw down the safety anchor bolts that connect the elements with the feed collector. It may be that the sleeves employed were made of a metal less malleable or less resistant than nickel, as this defect has been practically unknown wherever proper care has been taken in the construction or keeping up of boilers.

"(*i*) The liability of the upper generator tubes to fail by pitting or corrosion, and, in economiser boilers, the still greater liability of the economiser tubes to fail from the same cause."

The question of corrosion is by no means confined to Belleville boilers; it has to be dealt with in all navies and in connection with all types of boilers; as has been already stated, many cylindrical boilers have had their tubes destroyed by corrosion. No boiler, therefore, is free from it, but in no one has the question been more carefully studied or more satisfactorily solved than in the Belleville boiler. The rules drawn by the Belleville firm for the preservation of boiler tubes are extremely simple; they consist in completely filling the boilers with alkaline water when they are at rest, and in mixing a sufficient proportion of lime with the feed water under proper conditions, so that the water circulating through the economisers may be always alkaline. In the French Navy, where these regulations are compulsory, abnormal wear has never been reported.

Why have they not been applied on all British ships from the beginning? Why have many British engineers disputed the efficacy of such precautions, which were reasonable and sanctioned by actual experience? Belleville boilers cannot be held respon-

sible for the consequences that followed a voluntary disregard of this most explicit advice from the makers.

The Committee further states, indeed, "that the Engineer officers in charge of Belleville boilers have not been made acquainted with the best method of working the boilers, and that which experience has shown to be most effectual in preventing the pitting and corrosion of tubes."

How is it that this fact was not given as a sufficient explanation in connection with the corrosion pointed out? They ought to have been led to it by the statements of their delegates, who, having carefully inspected the economisers of the *Laos* after three years' uninterrupted service, found them perfectly sound.

The Committee's attention, moreover, should have been drawn to the fact that pitting or corrosion does not take place with the same intensity on all ships; that it is unheard of on some, while it occurs with particular intensity on others. Logically, then, they might have inferred from it that the fault was not with the boilers, but with the manner of working them.

"(*k*) The up-keep of the Belleville boiler has so far proved to be more costly than that of cylindrical boilers. In the opinion of the Committee this excess is likely to increase materially with the age of the boilers."

Among the ships that were taken by the Committee as a basis for their estimates named in paragraph 8 of the report there are some the defective construction of which has been duly acknowledged. These defects caused very large expenditures for overhauling which cannot be considered in the up-keep expenses. On the other hand, the want of experience of the men, pointed out by the Committee, must have had a share in these excessive expenses, for the up-keep of Belleville boilers is certainly less, contrary to the opinion of the Committee, when the engineering staff becomes more familiar with them.

The comparison with the up-keep of cylindrical boilers ought to include, for the sake of accuracy, the addition of the enormous cost of renewing the boilers after eight or ten years; Belleville boilers are free from it, as they last almost indefinitely when properly cared for. Further, when repairs or renewal are

found necessary it is not required that the ship's decks and beams must be torn up, nor that the ship be placed out of service, except for a short period.

"(*l*) The additional evaporating plant required with Belleville boilers, and their greater coal consumption on ordinary service as compared with cylindrical boilers, has hitherto nullified to a great extent the saving of weight effected by their adoption, and, in considering the radius of action, it is doubtful whether any real advantage has been gained. The Committee are not prepared without further experience to say to what extent this may not apply to other types of water-tube boilers."

First it must be remarked that the Committee acknowledges, at the time when its report was drawn, that it is not prepared to say whether other types of water-tube boilers are not subject to the same criticism. While this statement does not lessen the value of the report as regards the comparison between cylindrical and Belleville boilers, it takes away from it any authority as regards opposing another system of water-tube boilers to the latter, and is a direct reply to those constructors who attempted to use this report of the British Committee as a support for the superiority of their own systems.

Coming back to the discussion of clause (*l*), it must be remarked:

1st. That Belleville boilers have never required additional evaporating plants to be fitted in any war or mercantile fleet. The Messageries Maritimes mail steamers have no other evaporators than those which would be necessary, under any conditions, for the service of passengers and crew.

When stating abnormal water consumptions on English ships, the Committee should have inquired into the causes, when it would have been convinced that these conditions were due to defective construction, unskillful handling, or to an unsatisfactory arrangement of piping, which is so extensive on account of numerous auxiliary engines. Proof could have been obtained also, by means of the very great differences reported in the water consumption of various ships, that the boilers must not be blamed for it.

As regards coal consumption, it will further be seen that the comparative trials ordered by the Admiralty between similar ships fitted with Belleville and cylindrical boilers, and covering several thousands of miles, have all been in favor of the former.

The above quoted ten remarks from the report of the Boiler Committee have been answered, and it is evident that none of them is worthy of serious discussion. The very wording of this document indicates a certain prejudice, but it will be conceded that the discussion of this phase of the report is not wise here. It is better to examine how this report was received in England, where it had been so anxiously awaited. The groundless criticisms against Belleville boilers, the illogical conclusions, the inaccuracy of statements, did not escape the competent and impartial judges who were called upon to express publicly their opinion on the Committee's work.

First of all, the Secretary of the Admiralty, when submitting the Navy estimates to the House of Commons, expressed himself as follows ["Times," March 19, 1901]:

"Recently, as the result of agitation, Mr. Goschen appointed another Committee, and they have issued an *ad interim* report which unequivocally condemned the Belleville boiler, and said it was not the best. This places the Admiralty in a very peculiar situation, for while the Committee has condemned the Belleville boiler, it has added two recommendations which are entitled to equal weight. It is said that there are other boilers which might with advantage be used, but the Committee has not reported in favor of any of them. But, up to the present moment, the Committee has not had an opportunity of conducting experiments which would enable it to pronounce an opinion. * * *

"I heard stated that one of his Majesty's ships was drifting round a buoy in the East Indies, and I see reports from the commanding officer and the engineers stating that there is absolutely nothing to complain of in the working of her boilers, but she has made, under ordinary conditions, and with bad coal, a speed of 19.5 knots, and that she is leaving for the Persian Gulf, the exaggeration does appear to me so gross that it is necessary to guard against the danger that might arise if we were to accept

the whole of the view of the honorable member (Mr. Allan). (Cheers.")

There are all kinds of ships—battleships, cruisers and mercantile ships—running every day and all day with these boilers. Great Japanese battleships have been sent out to the East and battleships of our own have only within the last few days made runs which have given the most extraordinary satisfaction with these boilers. * * *

"The house must not believe that all the difficulties which are attributed to the manipulation of the Belleville boilers are peculiar to that boiler, for some of them are common to other boilers.

"I have said this in order to justify the position of the Admiralty. They accept frankly and freely the report of the Committee and they intend to make what the Committee has recommended. (Hear, Hear.) Moreover they intend to make it retrospective, as far as it possibly can be without delaying the completion of his Majesty's ships. If it is found that there is some other boiler so manifestly superior to the Belleville boiler, it is still open to the Admiralty to put it into other ships in the course of time; but they will not be frightened into any weakening of his Majesty's Fleet, in order to meet what they believe to be a fanciful view of the situation. (Hear, Hear.")

On the same date, the "Times" published the opinion of its technical correspondent about the Boiler Committee's report. This article should be quoted in full, but a few extracts will show its spirit.

"The interim report of the Committee upon Water-Tube Boilers has now been made public, and to an observer of the events who knows a little of the subject it appears a very threadbare, unconvincing production. Its recommendations, if acted upon by the Admiralty are of such far reaching importance to the Navy, and thereby to the country, that it should be carefully analyzed and the circumstances under which it was written seriously taken into account by all those who desire the most satisfactory results to be obtained therefrom for the good of the nation."

Proceeding further to name the members of the Committee, the correspondent goes on as follows:

"The gentlemen whose opinions upon this almost purely technical subject must necessarily sway the opinion of their fellow-members are: Mr. Milton, of Lloyd's, Mr. List, Mr. Bain and Mr. Smith.

"In these remarks the last-named gentleman need not be considered, because his opinion upon the principal point of the report differs from that of his fellow-members, and he refused to vote for the report as it stands. There remain, therefore, the other three gentlemen, upon whose shoulders it may be fairly considered that the bulk of the responsibility connected with the report must rest. They are first-rate men, of the highest integrity, with much experience in the mercantile marine, knowing thoroughly the requirements of its propelling machinery, both from commercial and technical standpoints, and with the fullest knowledge of cylindrical or tank boilers in their various forms; but I believe I am perfectly correct in stating that no one of them has ever constructed, or worked, or taken the responsibility of constructing or working, a set of water-tube boilers of any description for a steam vessel. Yet they are called upon to pronounce judgment and give expert opinion upon a subject of which they have no actual knowledge based upon personal experience, and in which, therefore, they must necessarily rely entirely upon such evidence as they have been able to gather in a somewhat limited period of time. There are many engineers, both at home and abroad (I do not include inventors or those connected commercially with any special type of boiler), who have spent years in constructing and working water-tube boilers, the presence of whom upon the Committee is conspicuous only by their absence.

"I hold no brief for M. Belleville, sentimentally; indeed, I should much prefer that a British boiler should be adopted in our Navy and a Briton receive whatever credit and gain are derivable therefrom. Commercially speaking, I consider M. Belleville has received more than enough money from this country to amply compensate him for his patents and any assistance he may have rendered in connection with his boiler which has now practically become common property; but, in a case of such im-

portance as that under consideration, personal feelings must not be allowed to bias one's judgment. The true position can only be ascertained by calm and critical examination from every point of view.

"Let us now take the report as it stands before Parliament and the public, and I venture to think it will clearly be seen by an impartial observer how the judges in this case have, unwittingly, been led into committing an error of justice."

The writer then examines each paragraph of the report, and points out how absurd it would be to endorse the Committee's conclusions on the mere pretense, not that the system is worse than others, but that it is *no better*.

He remarks that, while recommending four types of boilers to the exclusion of the Belleville, *so uncertain are the Committee of their ground*, that they urge the rapid completion of the three sloops and two second-class cruisers to be fitted with the boilers they recommend "in order that they may have some idea as to the value of these types for naval purposes!"

He further points out the contradiction between the suggestion of throwing the Belleville boiler aside and the opinion expressed in paragraph (10) "that the Admiralty were justified in regarding the Belleville as the most suitable type of water-tube boiler for the Navy, by reason of its long and satisfactory service at sea."

"In 1894, or, say, seven years ago, the Belleville boiler was considered the most suitable for adoption upon a large scale in our Navy, owing to the fact that it had then been working at sea, both in the mercantile and military marine, for a considerable number of years with satisfactory results. I fail to see how the Committee can prove that in this year of 1901 the Belleville boiler does not hold precisely the same position with regard to its competitors. There are certainly more of them afloat, not counting our own Navy, than water-tube boilers of any other type, and when it comes to years of service and continuous work at sea the Committee must know perfectly well that no other water-tube type of boiler can show one-tenth of the Belleville record. They have now been working seven years longer than they had in 1894; consequently, if the arguments of seniority,

or of extensive adoption, or long experience in working hold good, then the Belleville boiler still holds the palm. But no, the Committee ignore all this, and recommend, in a hazy kind of way, the adoption of all or sundry of four other types of boilers * * * ."

Going further with his examination, the writer properly points out that the Committee's opinion was formed after taking evidence from the Chief Engineers of vessels, " having given considerable trouble with their boilers, * * * who by virtue of their position, are held to a great extent responsible for the boilers' failure," and were placed in the alternative of either throwing blame upon themselves, or complaining of the boilers they had not known how to use; he further asks the following question, insisting on the true spirit of the Committee: " Did the Committee take evidence from the Chief Engineers of successful vessels which have been running at sea and doing excellent work for the past ten or twelve years?"

Coming to the paragraph in which it is argued that especially skilled men should be required to work Belleville boilers, and that the engineers interviewed by the Committee had not been made acquainted with the proper methods, the writer says:

"As for extra skill being required, they are worked by men of every nation in the world, and surely we can do as well. If the engineers were not made acquainted with the simple instructions connected with the working and preservation of boilers, most of the difficulties are easily accounted for."

About the abnormal coal consumption caused by evaporators and other auxiliary engines, the article continues as follows:

"The Committee have evidently been imperfectly informed upon this important subject. His Majesty's vessels fitted with Belleville boilers should not now consume more coal for auxiliary purposes than those fitted with the cylindrical type. The first-class cruisers were generally understood to be burning somewhere about eight tons a day for auxiliary purposes. On board a cruiser of the same class it was found that about three tons were sufficient to supply the necessary steam for certain auxiliaries. Steps were taken to verify this result, and it was

found to be perfectly correct. The chief engineers of the vessels consuming the extravagant quantity of coal were requested to visit the *Spartiate* and see for themselves whether her coal consumption was correctly reported or not. They saw, were satisfied, and returned to their ships to do likewise. It would appear from the report of the Committee that it is principally upon the evidence of these engineers that the condemnation of the Belleville boilers has been based. Further comment is superfluous."

The writer further examines each of the technical remarks that have already been discussed, and his arguments to the same effect as those set forth in the present note, lead to the same conclusion as to the value of the accusations.

These quotations from the technical correspondent of the "Times" having been rather long, it will be enough to point out other similar opinions from many well-informed persons.

Sir Edw. J. Reed, K. C. B., in a long letter to the editor of the "Times," March 22d, 1901, refuting the conclusions of the Committee, says: "* * * On observing the appointment of the Committee in September last, I remarked to an engineering friend, 'That Committee will be certain to report adversely to the Belleville boiler, for its members will have to get all their information at second hand, and will chiefly examine those men in whose hands that boiler has failed.'"

He then proceeds to remark that "the question put to the Committee about the selection of a type of water-tube boiler seems to imply that this form of boiler, whatever its merits, is to be got rid of unless it is considered superior to all its rivals. I do not, as a member of Parliament and a taxpayer, think this is quite the attitude for the head of the British Navy to assume * * *.

"* * * The report itself is one of the most singular documents I have ever read—so singular as to be accounted for only by the fact that the Admiralty's determination 'to have an interim report from the Boiler Committee as soon as possible' overbore the sense of the Committee. * * *

"But perhaps the most amazing part of the report is the Com-

mittee's enumeration, in clause 9, of what they regard as 'practical objections' to the Belleville boilers. With all respect to the professional gentlemen signing the report, I must say that this summary is the most curious instance of joint professional co-operation that I have ever seen. Some of their points are common to all water-tube boilers; some of them, where defects existed, have already been corrected; some of them do not exist in the recent Belleville practice of the Admiralty; and some of them —such as the objection to the use of separators—are beneficial additions to high-pressure boilers, whether Belleville or other. Such a clause as No. 9 could not possibly have been signed by any engineer well experienced in the use of Belleville boilers. * * *

"But great as may have been the troubles which beset this new branch of work from a scientific point of view, I cannot doubt that the human element has been a very grave cause of the breakdowns, such as they have been. Certain it is that there are many ships in our own and other Navies supplied with Belleville boilers in which no sort of danger or difficulty has ever been experienced. The Japanese have had warship after warship of the largest classes fitted with Belleville boilers and no complaint has ever been made of them. They are fitted in the powerful Chilian cruiser *O'Higgins*, and her trials out of Newcastle were made under the most disadvantageous circumstances, the English stokers striking for more pay on the very morning of the first trials. But the Chilian stokers, who happened to be on board, took the boilers in hand, and her two-days' trials were completed without difficulty of any kind. That ship, during three years of service, has since steamed 30,000 miles, often at the highest speed, and never has had a single tube burst or burned or proved bad. * * *

"I conclude by deprecating in the strongest manner the expenditure of additional public money upon any of the suggestions of this crude interim report, which rests upon no adduced basis of facts, and which is of a tendency most injurious to the Navy and the country. * * *

"Having had myself to deal professionally and responsibly

with many Belleville and other forms of water-tube boilers, I find the interim report an incoherent and an inconsistent document * * *."

The same opinion is again expressed in a letter to the "Daily Chronicle," March 14, 1901, by Mr. Fred. L. Jane, author of "The Imperial Russian Navy," "Warships of the World," "Torpedo Boats in Time of Peace and War," &c. A most competent man, indeed, to judge the work of the Committee.

" * * * The report as a whole scarcely tends to increased respect for the Committee, who upon at least one item have displayed imperfect knowledge of their subject * * * .

" * * * Therefore [of the proposed boilers] the Committee know little more than the man in the street * * * .

"In conclusion, the Committee cannot be congratulated on the net result of their labors. In more than one particular have they advertised ignorance, and the excessive condemnation of the Belleville will not meet favor with the best men here or elsewhere. It almost suggests a pandering to a newspaper agitation carried on by writers who, from internal evidence, are in some cases supremely ignorant of either naval needs or naval facts."

The opinion may also be quoted here of the prominent Italian shipbuilder, G. Orlando, who, having constructed the Belleville boilers for the Italian cruiser *Varese*, built in his shipyard, and having tried them, knows much about them. He wrote to the "Times," March 23, 1901, that, having read the interim report of the Committee, he was very much surprised at its conclusions and thought it to be his duty, for the sake of truth and good faith, to give his own opinion on the question.

He stated that he completely agreed with the conclusions of the technical correspondent of the "Times," above quoted, and declared that long and numerous trials were carried out with the *Varese* without any sort of trouble from the boilers; he refuted by facts the practical objections of the Committee, and concluded as follows:

"To sum up, I think that no other type of boilers could at the present time be supported by such statements, drawn from actual practice, as to justify a preference of one of them over the

Belleville system, and I am therefore perfectly determined not to change anything in the designs we have in hand or in the proposals we have submitted to the government for large power marine plants."

It would be easy to oppose to the report of the Committee the opinions of a great many members of Parliament or writers, which were brought forward in the House of Commons or in various newspapers; but the authority and competence of those who have already been referred to is enough to convince any impartial reader.

It is difficult to understand the reasons that led certain members of the Committee to criticise the Belleville boiler so severely. It seems probable, however, that the possible desire to open the way to the adoption of an English made boiler somewhat influenced their decision.

This prejudice would not be commented upon here had it not been made evident by the numerous discussions to which the report was subjected in England, as shown by the foregoing examples. It was still more apparent in the report made by the Committee on the comparative trials on two vessels of the same class, the *Minerva*, fitted with cylindrical, and the *Hyacinth*, fitted with Belleville boilers.

The first trials gave the results summarized in the annexed

| Table XXV. | *Minerva.* | *Hyacinth.* |
|---|---|---|
| LINE 46.—Thermal efficiency of the boilers: | *per cent.* | *per cent.* |
| At about 2,000 H.P. | 69.7 | 77.2 |
| 5,000 H.P. | 68 | 71.8 |
| 8,000 H.P. | 61.4 | 73.3 |
| LINE 47.—Actual evaporation per pound of coal, under the conditions of the trial: | *pounds.* | *pounds.* |
| At about 2,000 H.P. | 8.56 | 9.65 |
| 5,000 H.P. | 8.84 | 9.33 |
| 8,000 H.P. | 7.93 | 9.39 |
| LINE 49.—Equivalent evaporation (per pound of coal) at a steam and water temperature of 212° F.: | *pounds.* | *pounds.* |
| At about 2,000 H.P. | 10.26 | 11.46 |
| 5,000 H.P. | 10.33 | 11.00 |
| 8,000 H.P. | 9.27 | 11.03 |

table, quite in favor of the *Hyacinth* boilers, which have been taken, as well as all the following information, from an official document published by Eyre & Spottiswood, London, under the heading "(Navy) Water-Tube Boilers.—Report on Trials of H. M. S. *Hyacinth*, H. M. S. *Minerva* and R. M. S. *Saxonia*."

In order to lessen the disadvantage thus illustrated against cylindrical boilers, the Committee directed that thin spiral plates, so-called "retarders," be fitted inside the tubes of the *Minerva* boilers. Some improvement was observed, but the results still remained inferior to those of the *Hyacinth*, although the report affirms the contrary; the facts are shown by the following figures:

| Table XXVI. | *Minerva* (with retarders) | *Hyacinth.* |
|---|---|---|
| LINE 46.—Thermal efficiency of the boilers, *per cent*... | 68.4 | 73.3 |
| LINE 47.—Effective evaporation per pound of coal, *pounds*..... | 8.84 | 9.39 |
| LINE 49.—Evaporation from and at 212° F., *pounds*... | 10.34 | 11.03 |

If the advantage which actually appeared in favor of the Belleville had appeared in the reverse direction, no matter how slightly in favor of the *Minerva*, it is extremely doubtful if the Committee would have reported equal efficiency results.

In the calorimetric experiments the same tendency was shown to favor the *Minerva* boilers. In this vessel steam for these tests was taken between the regulating valve and the H.P. valve chest of the port main engines, so that it received the advantage of being superheated by the fall of pressure that took place behind the valve. In the *Hyacinth* it was taken in the stokehold on the boiler side of the separator and of the reducing and regulating valves; the results, therefore, were not comparable. However, the Committee declared that steam was practically dry in the *Hyacinth* up to 8,000 H.P., and contained from 4.7 to 6.4 per cent. moisture above that power, while in the *Minerva* it was practically dry at all powers.

If these results were not vitiated by the defective arrangement of the calorimeters it would be difficult to explain how these

very horsepowers, from 8,000 to 10,000, are those at which the *Hyacinth* engines showed greater efficiency than those of the *Minerva*, as engine efficiency diminishes in proportion as the steam is wetter.

Besides, Table XXVI still more clearly proves, though the Committee omitted to point it out, that the quality of the steam produced by the *Hyacinth* boilers is superior to that of the steam from the *Minerva* cylindrical boilers.

*Minerva.*

| | |
|---|---|
| LINE 9.—Mean pressure by gauge on the H.P. valve chest, pounds | 136 |
| LINE 10.—Corresponding temperature of saturated steam, degrees Fahrenheit | 358.5 |
| LINE 13.—Mean observed temperature in H.P. valve chest, degrees Fahrenheit | 345 |
| Fall of temperature, degrees Fahrenheit | 13.5 |

*Hyacinth.*

| | 8,000 H.P. Closed. | With exhaust. Open. | 10,000 H.P. Open. |
|---|---|---|---|
| LINE 9.—Mean pressure by gauge in H.P. valve chest, pounds | 194 | 192 | 220 |
| LINE 10.—Corresponding temperature of saturated steam, degrees | 385.1 | 384.3 | 395.4 |
| LINE 13.—Mean observed temperature in H.P. valve-chest, degrees | 391.6 | 389.1 | 394.1 |
| Excess of temperature, degrees | 6.5 | 4.8 | ... |
| Fall of temperature, degrees | ... | ... | 1.3 |

Therefore, in the *Minerva*, with 8,000 horsepower, the thermometer indicates a fall of temperature of 13.5 degrees as compared with the temperature corresponding to the gauge pressure, while in the *Hyacinth*, at 10,000 horsepower, this difference is only 1.3 degrees, and at 8,000 horsepower there is, on the contrary, a gain of 4.8 degrees and 6.5 degrees. And still the Committee affirms that the *Hyacinth* produces wet steam.

The Committee states in its report that the water consumption of the *Hyacinth* is far greater than that of the *Minerva*, and, without trying to determine the cause of water losses, attributes them to the boilers. Here again the want of proper care in these very important trials is evident.

Experiments were carried out at Devonport, December, 1901, on two boilers of the *Hyacinth*, then just returned from sea-service, in order to measure the loss of water due to the boilers alone, and to determine the cause of these losses. Measurements were made during six consecutive periods of 24 hours each; the subsequent examination of the boilers showed that the losses were due exclusively to leaks in the joints of the hand-hole doors of the junction boxes, the faces of which did not bear truly against each other, while the asbestos rings were of irregular thickness and defective composition. The joints were re-made under more normal conditions, and in a new trial, covering, like the former, a period of six times 24 hours, it was found that the loss had been reduced to less than one-tenth of its former amount.

It must be remarked that these boilers, like all the boilers of the British fleet, were made in England without any supervision or advice of the Belleville firm, and that no representative of this firm ever attended the trials. The makers and the engineers should have been thoroughly instructed about the boilers and how to get the best results, which was certainly not the case.

The Committee still continues its former methods when comparing the radius of action of both vessels. It was first assumed that the water losses in the *Hyacinth*, the cause of which has just been explained, limited her radius of action more than the coal consumption; this is evidently wrong, since these water losses are abnormal and avoidable.

Then, considering only the radius of action resulting from coal consumption, the Committee omitted to distinguish those outside elements which may bear upon it, although this investigation was upon a question of boilers only. In consequence the following bare figures were given:

The *Minerva*, at 7,000 horsepower, ran 2,640 miles and burnt 977 tons of coal (page 17, lines 30 and 31).

The *Hyacinth* ran 1,810 miles and burnt 676 tons of coal (page 16, lines 63 and 49).

Such are the material facts.

On comparing these figures it will be seen that the *Hyacinth*,

by burning the same quantity of coal as the *Minerva*, namely 977 tons, would have run

$$1{,}810 \times \frac{977}{676} = 2{,}616 \text{ miles.}$$

Therefore, comparing the radii of action corresponding to *the same amount of coal burnt*, the *Minerva* has an advantage of only 24 miles over the *Hyacinth;* that is to say, less than one per cent. This difference is almost insignificant in itself; but we shall see that, if the two types of boilers had been fitted in conjunction with engines and hulls of the same efficiency, all the advantage would then have been with the *Hyacinth's* boilers, and would be proportionately greater, which an impartial Committee should have pointed out.

It was shown, indeed, from the report, that the thermal efficiency of the *Minerva's* engines was better than of the *Hyacinth's* (16.7 per cent. against 15.1 per cent.).

This is a difference of 1.6 per cent. detrimental to the *Hyacinth*, which affects her radius of action. But the hull efficiency had also to be accounted for, since, with the same power, the *Minerva* had a better speed, as shown in the following table:

| *Hyacinth.* | | *Minerva.* | |
|---|---|---|---|
| Horsepower. | Speed, knots. | Horsepower. | Speed, knots. |
| 2,146 | 12.10 | 4.919 | 17.52 |
| 7.678 | 17.34 | 8,216 | 19.60 |
| 10,447 | 19.40 | 9,902 | 20.34 |

Therefore the *Minerva* was faster at 4.919 horsepower than the *Hyacinth* at 7,678 horsepower; 17.52 knots instead of 17.34.

Is it not strictly equitable, in order to strike a fair comparison *from the boiler point of view only*, that allowances should be made for elements whose influence is so considerable?

It is useless to insist on the fact that the *Hyacinth* had at her disposal on the run to Gibralter only 968 tons of coal, while the *Minerva* had 1,016 tons in her bunkers, *i. e.*, 48 tons, or 5 per cent., more.

Such were the grounds upon which, from the boiler point of view, the radius of action of both vessels was compared.

The true results of these trials, although set forth with an undeniable partiality, appeared so flagrantly contradictory to the conclusions of the report of the Boiler Committee that the question was brought before the British Parliament.

In the sitting of June 3, 1902, the First Lord of the Admiralty, answering a question as to "what decision had been arrived at as to the respective merits of the different types of boilers consequent upon the trials of H. M. S. *Minerva* and H. M. S. *Hyacinth*," acknowledged without hesitation that the Belleville boilers had been unduly criticised. His whole speech might be quoted, as it puts everything in the right light, with the most remarkable clearness; but a few extracts from it will be enough to show its general meaning.

First, is a sentence applying to those who wished to spread the belief that certain of the difficulties mentioned had originated with the Belleville boilers:

"Long before water-tube boilers were heard of, the Navy had these difficulties in the various forms of boilers that preceded them."

Then, immediately, an answer to the too favorable opinion of the Committee on the *Minerva* trials:

"When she got to Plymouth 'bird-nesting' had reached that point that if coal had not given out the vessel could not have gone any further, the tubes were partly, and in many instances completely, closed."

Further, referring to the difficulties experienced on a few vessels, he expressed himself as follows:

"Now, I wish at once to confess that with the Belleville boilers in the Navy we have had difficulties that apparently foreign navies had not to contend with. I may summarize the cause of these difficulties under four heads—inferiority of manufacture, improper management, higher pressure and greater use. * * *

"But I wish, with all emphasis, to say this after experience of the Belleville boilers—that the difficulties we met with would have been met with in any other type of water-tube boilers, and what

we have learned from the Belleville boilers we shall turn to account with other types of boilers we use."

Going on with an examination of the services rendered by Belleville boilers in the British fleet His Lordship did not hesitate to declare, although in very moderate terms, that the real facts did not agree with the opinion of the Boiler Committee.

"Now I agree and disagree with the verdict of the Boiler Committee. I disagree to this extent—that I do not think the absolute condemnation of the Belleville boiler by the Committee can be assented to to the extent the words they use would imply, in face of the experience of other nations with the boiler, experience we are now gaining with our battleships. * * *

"To this extent I disagree with the Boiler Committee—that I believe the Belleville boiler, well manufactured and well managed, will fulfil conditions that make it a reliable boiler for the Navy for sea use in peace or war. * * *

"To illustrate why I have said this about the Belleville boiler I will allude to two classes of battleships, one of which has wholly and the other nearly passed into commission—the *Canopus* and the *Formidable*. On the whole, I have the most excellent reports of their boilers, and I am very glad the *Formidables* have got Belleville boilers and not cylindrical. * * *

"The experience gained in the cruisers has held good, and the reports we have received about the battleships are undoubtedly at present satisfactory. * * * I will turn to our own Admirals who command squadrons in which are ships with these water-tube boilers. There are four of such squadrons—the Channel Squadron, the Mediterranean Squadron, the East Indian Squadron and the China Squadron. I cannot extract from the commander-in-chief of one of these squadrons a condemnation of the water-tube principle."

No doubt this opinion may be understood to apply to all water-tube boilers; but no other water-tube system than the Belleville existed on battleships and big cruisers at the time it was formulated; therefore the Admiralty could base its favorable opinion on no other type of water-tube boilers.

Coming back to the Bellevilles:

"There are twelve ships on the China Station with these water-tube boilers, four of them battleships and the others large and small cruisers. I have been reading only today a private letter from the Inspector of Machinery at Hongkong, and he speaks in the highest terms of the machinery of all of them, with the exception of the *Glory's*, which, though it has given a great deal of trouble, is now absolutely efficient. But that again was a case of mismanagement on the part of the *personnel*. * * *

"As ships go on in their commission the extra consumption of coal decreases. I will give your lordships a striking instance of that. I take the case of the *Canopus*, which has now been in commission in the Mediterranean for over two years. The average coal consumption of the *Canopus*—the auxiliary coal consumption in harbor—for the six months ended December 31, 1900, was 17.2 tons per day. The same coal consumption for the six months ended December 31, 1901, was 10.2 tons per day. The lowest daily record during the first period of six months was 9.1, 11.5 and 12.6 tons, and during the second period of six months, 6.8, 6.9 and 6.85 tons, and so on. I could give other instances where the assiduous attention of the engineers, the better understanding of the machinery, the detection of weak points in manufacture, and their gradual elimination have slowly worked down the consumption of coal to a more reasonable figure. * * *"

It will be seen that this discourse refutes all the reproaches of the Boiler Committee, and it will be admitted that the First Lord of the Admiralty, before delivering it, had collected more precise information than the Committee and had also a better sense of the true interests of the Navy.

This judgment on the work of the Committee was again supported, during this same sitting of the House of Lords by the predecessor of Lord Selborne: "* * * Those were the drawbacks to which he alluded, of inferior manufacture and the insufficient training of those who were put in charge of those engines. * * *

"Cases like those of the *Hermes*, the *Europa*, and many others which especially affected the public mind with reference to the

water-tube boilers were simply due to the want of management on the part of the engineers. The difficulty lay, not only with the stokers, but with the whole of the engineers of the Navy, who had to unlearn something they had learned before and to learn afresh something they had not learned before. * * *

"While we have the report of the evidence against the Belleville boiler, I myself have not seen any evidence or any arguments yet produced in favor of other boilers. I do not know whether my noble friend has had any evidence on that subject, but I can scarcely think he has. * * *

"With reference to the condemnation of the Belleville boilers, my noble friend produced, if I may say so, evidence on the other side, though he did not mention the actual fact, from the commanders of all our squadrons. He stated very emphatically that he attempted to extract condemnation of the water-tube boilers, and that he had not been able to extract such condemnation. They were all in favor of what boilers? Of the Belleville boilers, which have been condemned by the Boiler Committee. * * *"

It has now been sufficiently proved that the report of the Boiler Committee can not be taken into serious consideration, neither as to accuracy of fact nor for its technical value.

Still the reproaches it contains are the strongest weapons used by competition, for which reasons they have had to be discussed at length.

The impartial readers of this article will, do doubt, be convinced that no serious objection has been raised against the Belleville boiler, unless it be common to all water-tube boilers.

The results it continues to give are the best proofs of its superiority.

As regards its endurance, England itself gave striking examples with the 1903 naval maneuvers, which were unusually important. Out of twenty-five ships that played their part in them, twenty-one were fitted with Belleville and the four others with cylindrical boilers; one serious accident only was caused by boilers, and that on the *Blake*, one of the cylindrical-boilered ships.

Among the vessels which were submitted to this severe test,

covering three months, the *Spartiate*, fitted with Bellevilles, had just completed a run from Plymouth to Hongkong and return, in three months, and, in order to join the squadron in time, had been forced to keep up a speed of 19 knots for 28 hours, after having made a forced cruise of over 29,000 miles. During the maneuvers, she had an opportunity of steaming at 18 knots for 96 hours. When the fleet returned to the harbor, this cruiser had covered 25,000 miles in five months, often at her maximum speed, without the slightest difficulty having been experienced with her boilers. This achievement may be considered as a *record* for war ships.

It must be noted that the reputation of the *Spartiate* was the worst in the British Navy, and that it was the general opinion that nothing could ever be got out of her.

English newspapers pointed out these achievements, and many of them, that had first followed the clever campaign against the Belleville and endorsed the conclusions of the Boiler Committee, did not hesitate to acknowledge their mistake in the presence of the above facts.

It is therefore likely that the Belleville boiler will really benefit by these attacks, and, being better known because it has been more widely discussed, it will have a wider field of usefulness.

Has the Belleville boiler reached its final period of improvement? This is not likely, since the Société des Etablissements Delaunay Belleville, which succeeded in August, 1903, to the Société des générateurs Belleville, have inherited all the perseverance in the fight for progress which distinguished the earlier firm throughout more than a half century, and will not hesitate to undertake new achievements.

Admitting for the moment, however, that the present type cannot be improved without difficulty and must remain as it is for a period, it will still be a perfectly safe and most efficient boiler of extreme durability, because of the special care exercised in its construction and in the selection of the materials from which it is made. The past must speak for its future.

If it be the good fortune of this article to give the reader a more complete understanding of the Belleville boiler and to

controvert, even in part, the many attempts to depreciate it, the writer will be well satisfied.

It will be an added satisfaction, however, if the reader shares the writer's admiration when following, step by step, the work of Mr. Julien Belleville, the creator not only of the boiler that bears his name, but, generally speaking, of the water-tube boiler. Many of his inventions have been only mentioned or have been passed over in silence; only those have been emphasized which are actual links of the chain connecting the 1850 boiler with the 1903 type. There still remains, between these two stages, an enormous sum of efforts, the mark of increasing labor supported by highly gifted intelligence, that ranks him among the most illustrious inventors, worthy the respectful homage of all.

# PROGRESSIVE TRIALS OF U. S. BATTLESHIP *MAINE*.

FURTHER DATA IN CONNECTION WITH "PROGRESSIVE TRIALS OF BATTLESHIPS," PUBLISHED IN VOL. XIV, No. 1, FEBRUARY, 1902.

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NAVY DEPARTMENT,
WASHINGTON, D. C., *March 11, 1904.*

Sir: We have the honor to report below the results obtained on the progressive trial of the U. S. S. *Maine*, held on the Barren Island course, in Chesapeake Bay, on October 7, last.

The methods used were practically the same as were employed during the progressive trials of the *Alabama*, *Massachusetts* and *Kearsarge*, over the same course, in November and December, 1901.

A record of the data recorded on the trial is appended, consisting of Appendix A, giving the deck record of the progressive trial, and Appendix B, giving the reduced data of the trial.

A curve sheet showing the results of the trial as plotted is submitted herewith, on which are shown the *speed curves* with and against the tide, plotted from the points established by the progressive speed runs, the *mean speed curve* and the corresponding *horsepower curve* from data computed from these runs.

While a short series of friction runs was made after the progressive-speed runs, the data obtained therefrom was so unsatisfactory that it has not been considered necessary to extend this report to cover their analysis, as was done for the *Alabama*, *Kearsarge* and *Massachusetts*.

The delay in submitting this report has been due principally to the fact that circumstances rendered it necessary to use the ship's indicators during the trial. It was found necessary to have these indicators standardized at the New York Yard, and

this could not be begun until the *Maine* had returned from her trip to San Juan.

A report identical with the above is submitted today to the Chief of the Bureau of Construction and Repair.

Very respectfully,

D. W. TAYLOR,
*Naval Constructor, U. S. N.*
M. E. REED,
*Lieutenant, U. S. N.*

TO THE CHIEF OF BUREAU OF STEAM ENGINEERING.
Navy Department.

BRIEF RECORD OF TRIAL.

Reported by D. W. Taylor, at Speed Recorder.
Forward observer, Lieutenant Holden; after observer, Lieutenant Beecher.

| No. of run. | Direction of run. | Entered course about— | Stop-watch time on course. | | Nature of record from instruments. | Remarks. |
|---|---|---|---|---|---|---|
| | | | *Min.* | *Sec.* | | |
| 1 | N. | 10°32 | 3 | 25.1 | Good. | Course steered while on the mile was parallel to buoys, but usually some distance to the westward of them. Depth of water on the courses steered was probably materially below twenty fathoms. |
| 2 | S. | 10°50 | 3 | 27 | Do. | |
| 3 | N. | 11°7 | 3 | 23 | Do. | |
| 4 | S. | 11°28 | 3 | 32.5 | Do. | |
| 5 | N. | 11°49 | 3 | 23 | Do. | |
| 6 | S. | 12°05 | 3 | 51.5 | Do. | |
| 7 | N. | 12°23 | 3 | 47 | Do. | |
| 8 | S. | 12.38 | 4 | 26.5 | Do. | |
| 9 | N. | 12°57 | 4 | 45 | Do. | |
| 10 | S. | 1°15 | 5 | 45 | Do. | |
| 11 | N. | 1°35 | 5 | 41 | Do. | |
| 12 | S. | 1°57 | 8 | 38 | Do. | |

WIND AND WEATHER DURING TRIAL

| Time. | Direction of wind. | Force of wind. | Condition of sea. | Bar. | Thermometer, dry bulb. |
|---|---|---|---|---|---|
| 10 | S. E. | 3 | Smooth. | 30.38 | 71 |
| 11 | Do. | 3 | Do. | 30.38 | 71 |
| 12 | S. | 3 | Do. | 30.36 | 72 |
| 1 | S. S. E. | 2 | Do. | 30.34 | 72 |

## Appendix A.

### DECK RECORD OF PROGRESSIVE TRIAL.

Name of vessel—*Maine*.

Vessel undocked—October 3, 1903.

Condition of bottom when undocked—fresh painted.

Painted with McInnes Anti-Fouling.

Itinerary from undocking to date of trial:

Newport News till October 6.

Left Newport News October 6.

Reached Barren Island course same day.

Date of trial—October 7.

Place of Trial—Barren Island course.

Progressive trial began about 10·30, local time.

Progressive trial ended about 2, local time.

Before trial, at 10 A. M., draught forward, 24 feet 3 inches; aft, 24 feet 6½ inches.

After trial, at 2·30 P. M., draught forward, 24 feet 2 inches; aft, 24 feet 6 inches.

Assumed trial conditions: Draught forward, 24 feet 2½ inches; aft, 24 feet 6¼ inches.

Mean draught, 24 feet 4⅜ inches.

Density of water on course, 1.018.

Determined by former observations checked by test October 7, 1903.

Trial displacement, 12,755 tons.

Tidal data from chart of course and tide tables for 1903:

| | | |
|---|---|---|
| H. W. on course | 2·10 P. M. | |
| L. W. on course | 8·07 A. M. | |
| Before ebb—H. W. slack on course | 5.23 A. M. | 5·55 P. M. |
| Before flood—L. W. slack on course | 11·27 A. M. | |
| Maximum flood on course | 2·45 P. M. | Maximum strength by tables 0.7 knot. |
| Maximum ebb on course | 8·27 A. M. | Maximum strength by tables 0.8 knot. |

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APPENDIX B.

## RECORD OF DATA TAKEN ON PROGRESSIVE S

| No. of run. | Direction of run. | Approximate time of entering course. | Time on course, in seconds. | | | | Revolutions of shafts. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Starboard. | | | | Port. | | | |
| | | | By stop watch. | From Weaver recorder | | Used in calculations. | On course by Weaver recorder | | Taken in engine room. | Used in calculations. | On course by Weaver recorder | | Taken in engine room. | |
| | | | | Forward observer. | After observer. | | Forward observer. | After observer. | From counter at beginning and end. | | Forward observer. | After observer. | From counter at beginning and end. | |
| 1 | N | 10·32 | 205.1 | 205.38 | 205.52 | 205.45 | 418.36 | 418.84 | 117.00 | 418 60 | 421.73 | 422.03 | 128.50 | |
| 2 | S | 10·50 | 207.0 | 207.66 | 208.34 | 208.0 | 417.38 | 418.94 | 118.60 | 418.16 | 418.90 | 420.54 | 120.60 | |
| 3 | N. | 11·70 | 203.0 | 203.56 | 204.10 | 203.83 | 406.70 | 407.64 | 121.50 | 407.17 | 419.80 | 420.86 | 126.72* | |
| 4 | S | 11·28 | 212.5 | 212.84 | 213.36 | 213.10 | 421.15 | 422.25 | 118.00 | 421.70 | 433.87 | 434.92 | 123.42 | |
| 5 | N | 11.49 | 203.0 | 203.11 | 203.83 | 202.97 | 402.72 | 402 00 | 120.00 | 402.36 | 411.71 | 411.25 | 123.60 | |
| 6 | S | 12.05 | 231.5 | 231.73 | 231.78 | 231.75 | 410.86 | 410.76 | 107.49 | 410.81 | 428.40 | 428.42 | 114.13 | |
| 7 | N | 12·23 | 227.0 | 227.05 | 227.25 | 227.15 | 376.47 | 376.75 | 101.16 | 376.61 | 389.51 | 389.61 | 101.36 | |
| 8 | S | 12·38 | 266.5 | 266.38 | 266.06 | 266.22 | 419.32 | 418.76 | 98.8 | 419.04 | 411.28 | 410.72 | 92.80 | |
| 9 | N | 12·57 | 285.0 | 284.86 | 284.42 | 284.64 | 369.64 | 369.33 | 81.35* | 369.48 | 361.20 | 360.90 | 75.80 | |
| 10 | S | 1·15 | 345.0 | 345.98 | 345.12 | 345 55 | 402.17 | 401.01 | 69.87 | 401.59 | 430.72 | 429.78 | 74.61 | |
| 11 | N | 1.35 | 341.0 | 341.15 | 340.76 | 340.95 | 346.08 | 345.84 | 61.13 | 345.96 | 350.78 | 349.20 | 61.64 | |
| 12 | S | 1.57 | 518.0 | 518.48 | 519.05 | 518.76 | 430.18 | 429.82 | 49.42 | 429.00 | 432.42 | 431.78 | 50.00 | |

* Not reliable.

FRICTION RUNS

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | ... | ... | ... | ... | ... | ... | ... | ... | 19 | ... | ... | ... | 22 |
| 14 | ... | ... | ... | ... | ... | ... | ... | ... | 24.5 | ... | ... | ... | 27 |
| 15 | ... | ... | ... | ... | ... | ... | ... | ... | 30 | ... | ... | ... | 30 |
| 16 | ... | ... | ... | ... | ... | ... | ... | ... | 35 | ... | ... | ... | 35 |

PENDIX B.

## ESSIVE SPEED TRIAL OF U. S. S. "MAINE."

| Port. | | | Apparent speed, knots. | Mean revolutions per minute. | Indicated horsepower, by cards. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Starboard. | | | Port. | | | |
| by order | Taken in engine room. | | | | | | | | | | |
| After observer. | From counter at beginning and end. | Used in calculations. | | | H. | I. | L. | H. | I. | L. | Total average for run, both engines. |
| 2.03 | 128.50 | 421.88 | 17.52 | 122.71 | Top 1,076.2 | 772.7 | 1,270.6 | 1,057.2 | 768.0 | 1,215.5 | 12,142.0 |
| | | | | | Bot. 1,071.7 | 721.0 | 1,190.7 | 1,011.5 | 719.6 | 1,267.3 | |
| 0.54 | 120.60 | 419.72 | 17.31 | 120.83 | 1,042.5 | 727.5 | 1,254.0 | 1,004.5 | 652.8 | 1,083.5 | 11,512.3 |
| | | | | | 1,033.5 | 714.9 | 1,156.7 | 957.8 | 1,034.8 | 1,194.6 | |
| 0.86 | 126.72* | 420.33 | 17.66 | 121.78 | 735.5 | 918.9 | 1,199.5 | 873.8 | 907.8 | 1,229.5 | 11,515.8 |
| | | | | | 741.6 | 886.9 | 1,048.5 | 895.0 | 823.3 | 1,255.5 | |
| 4.92 | 123.42 | 434.40 | 16.89 | 120.52 | 708.0 | 933.0 | 1,171.5 | 850.2 | 880.8 | 1,181.0 | 11,429.9 |
| | | | | | 692.2 | 917.0 | 1,080.3 | 829.4 | 928.4 | 1,258.1 | |
| 1.25 | 123.60 | 411.48 | 17.74 | 120.27 | 690.2 | 918.7 | 1,121.0 | 785.5 | 1,127.5 | 1,131.6 | 11,542.5 |
| | | | | | 693.3 | 887.8 | 1,060.5 | 796.0 | 1,147.2 | 1,183.2 | |
| 8.42 | 114.13 | 428.41 | 15.53 | 108.64 | 591.0 | 780.6 | 730.8 | 671.0 | 771.2 | 683.8 | 8,565.5 |
| | | | | | 569.5 | 746.8 | 669.9 | 712.7 | 799.8 | 838.4 | |
| 9.61 | 101.36 | 389.56 | 15.85 | 101.18 | 516.0 | 441.9 | 561.1 | 543.1 | 443.1 | 573.0 | 6,177.5 |
| | | | | | 477.0 | 428.7 | 522.3 | 563.1 | 474.5 | 633.7 | |
| 0.72 | 92.80 | 411.00 | 13.52 | 93.54 | 463.0 | 401.3 | 499.3 | 400.4 | 304.2 | 404.9 | 4,948.0 |
| | | | | | 430.3 | 397.8 | 462.8 | 418.9 | 311.2 | 453.9 | |
| 0.90 | 75.80 | 361.05 | 12.65 | 76.99 | 272.2 | 200.0 | 247.0 | 244.3 | 151.4 | 214.6 | 2,648.1 |
| | | | | | 266.0 | 202.5 | 236.0 | 264.4 | 163.2 | 186.5 | |
| 9.78 | 74.61 | 430.25 | 10.42 | 72.21 | 212.7 | 144.1 | 172.1 | 237.1 | 158.7 | 200.9 | 2,292.9 |
| | | | | | 190.8 | 141.6 | 164.5 | 272.9 | 151.7 | 245.8 | |
| 9.20 | 61.64 | 349.99 | 10.56 | 61.23 | 145.1 | 94.1 | 110.5 | 144.5 | 95.1 | 119.4 | 1,421.4 |
| | | | | | 135.4 | 88.9 | 103.1 | 151.7 | 93.5 | 140.1 | |
| 1.78 | 50.00 | 432.10 | 6.94 | 49.80 | 83.9 | 57.5 | 64.0 | 96.9 | 48.3 | 61.7 | 828.9 |
| | | | | | 76.8 | 56.5 | 54.9 | 107.1 | 54.1 | 67.2 | |

Not reliable.

### TION RUNS.

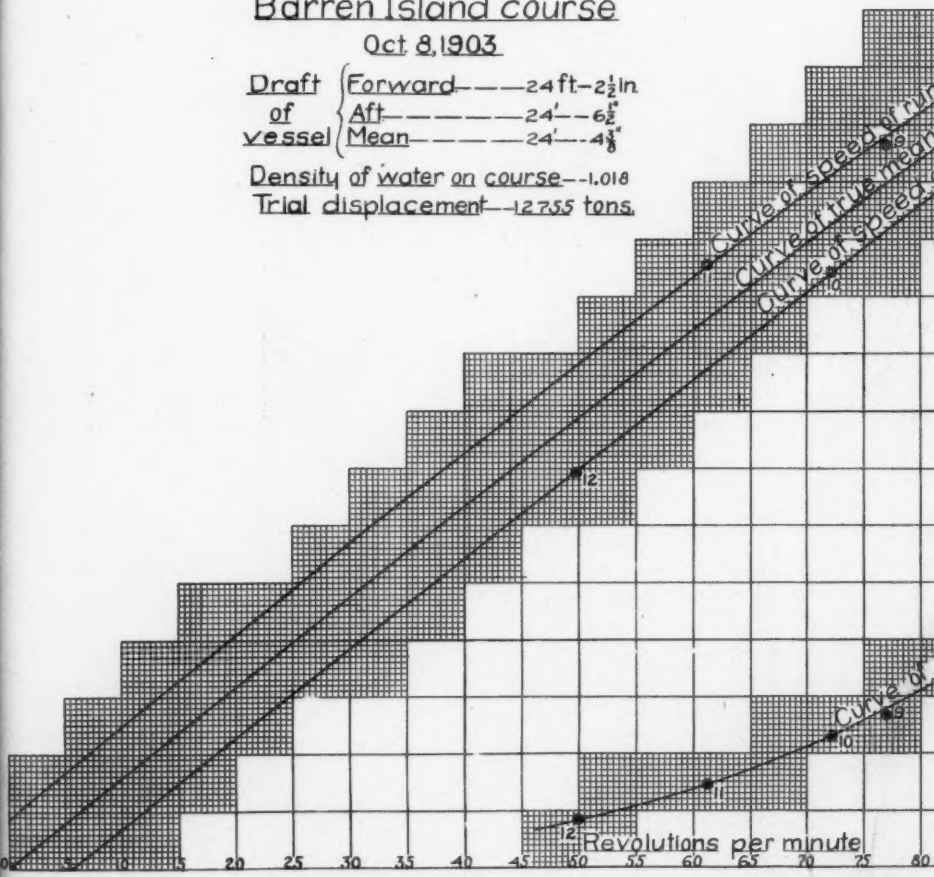
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ... | 22 | ... | ... | ... | 17.6 | 16.5 | 9.4 | 19.0 | 14.3 | 15.4 | 200.9 |
| | | | | | 16.9 | 20.3 | 8.0 | 20.9 | 17.2 | 15.4 | |
| ... | 27 | ... | ... | ... | 27.3 | 28.4 | 10.3 | 30.0 | 21.5 | 19.0 | 278.4 |
| | | | | | 26.2 | 27.9 | 10.3 | 28.9 | 25.0 | 23.6 | |
| ... | 30 | ... | ... | ... | 37.0 | 37.0 | 12.7 | 33.3 | 26.1 | 23.2 | 352.7 |
| | | | | | 35.7 | 38.5 | 12.6 | 39.3 | 32.1 | 25.2 | |
| ... | 35 | ... | ... | ... | 43.2 | 50.7 | 24.6 | 43.2 | 35.5 | 24.6 | 458.1 |
| | | | | | 41.6 | 52.8 | 18.4 | 50.0 | 39.9 | 33.6 | |

# Results of progressive trials of U. S. S. Maine on Barren Island course

Oct. 8, 1903

Draft of vessel: Forward——24 ft-2½ in.
Aft————24'--6⅝"
Mean————24'--4⅜"

Density of water on course--1.018
Trial displacement--12755 tons.



Curve of Indicated Horse-Power
Indicated Horse-Power
Speed in Knots per hour
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
70
75
80
85
90
95
100
105
110
115
120
125
130

# CORROSION OF BOILER TUBES.

By Rear Admiral John D. Ford, U. S. N., Member and President.

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Prepared from reports made by Lieutenant Commander H. C. Cleaver, U. S. N., and by Commander W. C. Eaton, U. S. N., being a continuation of the experiment made by Lieutenant W. H. Chambers, U. S. N., and published in the Journal, Vol. XIV, No. 2, May, 1902.

On January 18, 1901, the Bureau of Steam Engineering of the Navy Department drew up a letter directing the Naval Inspector of Engineering Material for the Pittsburg District to carry out a series of tests in order to ascertain the relative corrodibility of lap-welded Bessemer steel, lap-welded iron, seamless cold-drawn steel, and seamless hot-drawn steel boiler tubes. All of the samples were to be obtained from the same company. The letter also contained instructions as to the method of carrying out the experiments.

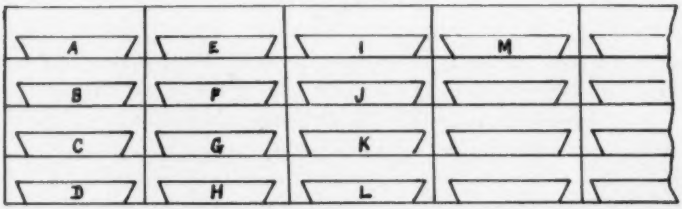
The National Tube Company generously offered the use of their laboratory at McKeesport, to bear the expense of installing the necessary apparatus, to furnish the sample tubes, to assist in conducting the tests, and to direct the photographer to make the necessary photographs by which to illustrate the nature of the corrosion.

The Bureau's letter directed the tests to be made in twelve tanks, each tank to contain sixteen samples, and samples from the top, middle and bottom of the steel ingots to be placed in the same tank. It further directed that samples be shifted in their position each week, so that at the end of a period of sixteen weeks each sample should have occupied consecutively every position in the tank in which it was placed, and at the end of each such period the samples to be taken from the tanks, cleaned with a brush, but not scraped, washed, dried, weighed

and photographed, the results tabulated and forwarded to the Bureau, together with the photographs and a report. The reports upon which this article is based are those made at the expiration of the first, second, third and fourth periods of sixteen weeks.

The tests were carried on in a room adjoining the chemical laboratory of the National Tube Company, the twelve tanks necessary being fitted against the wall on one side of the room, in three vertical rows of four tanks each, the tanks being lettered as shown by the following sketch of their arrangement:

SKETCH NO. 1.




ARRANGEMENT OF TANKS.

The tanks were porcelain lined, to guard against corrosion, and were partly filled with distilled water, the water level in the lowest row being almost twelve inches above the floor, and in each of the other rows almost eighteen inches above that next below.

Additional tanks were also fitted to allow the metallurgist of the company to carry on other tests under conditions differing from those defined in the Bureau's instructions.

A Westinghouse vertical air compressor was secured to the wall of the room, near the window, and the suction pipe led to the outside air, in order to secure a supply of air as pure as possible.

Four glass pipes, as shown in sketch No. 2, with small holes one inch apart along their upper sides, and closed at one end, were placed in the bottom of each tank and connected at their open ends by rubber tubes to stop cocks, for regulating the supply of air.

SKETCH No. 2.

It was found impracticable to connect all these tubes with the air compressor by a system of glass and rubber tubes and glass stop cocks, as was required by the instructions, so iron pipes were used, no parts of which, however, were in the water in the tanks.

The air supply was ample and continuous, and was easily regulated by the stop cocks, so that at no time could any water have been drawn back into the pipes from the tanks. The installation of the iron pipes, instead of the glass and rubber tubes required, is not believed to have had any influence upon the results obtained. Only twice during the first period of sixteen weeks was it found necessary to stop the compressor for adjustment, and then only for very short intervals. The manner of conducting the tests for the fourth period of sixteen weeks differs from previous periods, in that the air was shut off from Saturday evening until Sunday evening of each week, the works not running during these intervals.

In placing the sample pieces in the tanks they were so placed as to rest on two of the glass tubes, with about one-third of the sample projecting over each tube, thus insuring a good distribution of air.

The samples were made six inches in length, from tubes made especially for the purpose, and were all of the same diameter, three inches outside, and the same gauge, No. 9 B. W. G.

The lap-welded tubes were made from the same ingot. After the usual discard was made the slabs from the ingot were numbered consecutively, number one slab being next to the discard from the top of ingot.

The tubes were subjected to the same physical tests as required for boiler tubes. The test pieces were examined for surface defects, and those that would not have passed this inspection for boiler tubes were not used in the tests.

After weeding out from those remaining, the necessary num-

bers were taken from as near as possible to the top, the middle and the bottom of the ingot. In the column "No. of sample," in the table for lap-welded tubes appended, the first figure indicates the slab number, and the second figure the tube number from that slab. The appended tables are not the full tables given in the reports, but from each tank are given the results obtained from the steel samples from the top, middle and bottom of ingots, respectively, showing the least and the greatest amount of corrosion; and for the charcoal-iron samples, the samples from each tank showing the least and the greatest amounts of corrosion. The tables giving a recapitulation and average of the results obtained cover the entire set of sample tubes experimented upon. In the tables care has been taken to mark by an "X" those samples which were the half of the tube containing the weld, the weld being left in the middle line of the sample to ascertain if it would affect the relative corrodibility of the metal.

In some cases the two halves of the same tube sample were not used, one-half being rejected for surface defects, as for the purposes of the experiment, as has been before stated, it was deemed best to take the samples from as near the top, middle and bottom of the ingot as possible after rejecting the defective pieces.

The identifying numbers were stamped into both the convex and the concave sides of the samples to insure that they would not be effaced by the corrosion, and were examined from time to time during the experiment to ascertain if they were still legible.

For the purpose of the photographer a simpler system of identification was used. Labels were pasted on the tubes, the letter of the tank and consecutive numbers from 1 to 16 being used. These photograph numbers and the letters were entered in their proper column in the tables—the tables connecting the two different systems of numbering.

According to instructions, each tank containing steel tubes was filled with samples from the tops, middles and bottoms of the ingots, in order to insure that the tube from these three locations would be acted upon by exactly the same influences.

Thirty-three billets from the same ingot, each 16 inches long and 4½ inches in diameter, so marked as to identify the locality, top, middle and bottom, of the ingot from which it was taken, and its relative position in that location, were supplied by the Pennsylvania Steel Company, from which to make the seamless-drawn tubes. Of these billets the first six from each location were used for the manufacture of the cold-drawn tubes, and the remainder for the hot-drawn.

The cold-drawn tubes were made in the usual manner, by hot piercing, hot swedge rolling and cold drawing. In the column, "No. of sample," T, M and B indicates what portion of the ingot the billet was taken from; the figures next to these letters indicate the number of the billet.

The next letters, P and O, indicate whether the sample came from the pointed or open end of the tube as drawn, as it was found necessary to take two samples from each tube on account of the small number of billets supplied. In the case of these tubes "X" in the table was used simply to indicate the second half of the specimen, there being no welds.

The hot-drawn tubes were made by piercing hot and then hot drawing, no rolling or swedging being done. After leaving the piercing machine one end was closed, and after two draws the other end was closed, and the tube cut in two. The tubes marked D in the column, "No. of sample," are those from the ends pointed after the second pass through the dies. Both ends were given three more passes, so those marked D were drawn twice in one direction and three times in the other, while those not so marked received all the five passes in the same direction. These tubes were reheated after leaving the piercer and after each draw. All other marks are the same as for the cold-drawn tubes.

Before placing the samples in the tanks they were weighed to the nearest gramme, their surfaces, including the edges, measured as near as practicable to the nearest one-hundredth of an inch, and the results tabulated.

While in the tanks the samples were kept covered at all times with distilled water, standing at least one inch over the highest part of the samples. The water in each tank was tested with blue

litmus paper at the end of each period of seven days, and at no time showed indications of acidity. At the end of each period of seven days each sample was shifted along to the next position, so that each sample made a complete round of the sixteen positions in the sixteen weeks. Conditions for all twelve tanks were kept as nearly the same as possible, the only difference noted being that in shifting the samples the temperature of the water was found to be slightly different, due to the relative position vertically of the tanks, the greatest temperature being found in those tanks farthest removed from the floor of the room.

At the end of the sixteen-week periods all the samples were taken out, washed in clean water with a stiff brush, and carefully weighed to the nearest gramme and the results tabulated. After the tubes were washed in clean water and weighed it was found that when dry, the surface became covered with a thin film of reddish oxide, which it was concluded would seriously interfere with getting a clear definition of the corrosion in the photographs. Washing the tubes in alcohol to rid them of this objectionable oxide was tried, but with indifferent success. The metallurgist of the company then suggested that the samples should be dipped in hydrochloric acid to remove the oxide, then immediately dipped in a tub of clear water and then in ammonia water to thoroughly remove the acid. Upon his assurance that all traces of the acid would be removed by these baths, his recommendation was adopted; the samples were given two washes each in distilled water and in ammonia, the baths in each aternately. They were then dipped in distilled water and dried with a cloth. Finally they were dipped in an alcohol bath and dried with a cloth. This treatment had the desired effect, and the photographs obtained very fairly defined the pitting and general corrosion. In one of the additional tanks, three cubic centimeters of strong hydroxide (KOH) was added to the distilled water, and in this tank were placed eight samples of lap-welded steel tubes, not used for the other tanks. The alkalinity of the solution was not determined, nor was any additional KOH added during the test. In all other respects the conditions were the same as in the twelve tanks in which

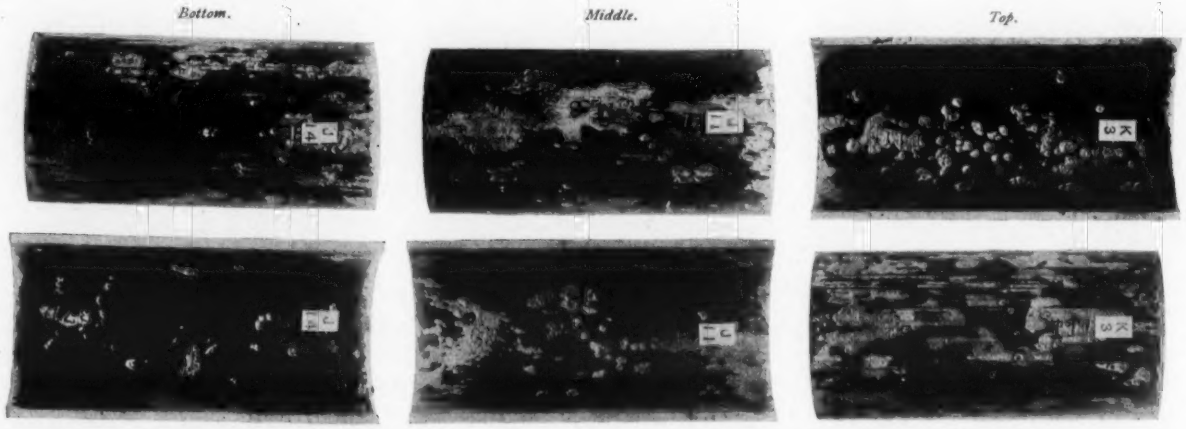



Plate I.—Hot-Drawn Seamless Steel Tubes, Showing Least Amount of Corrosion After Sixteen Weeks.

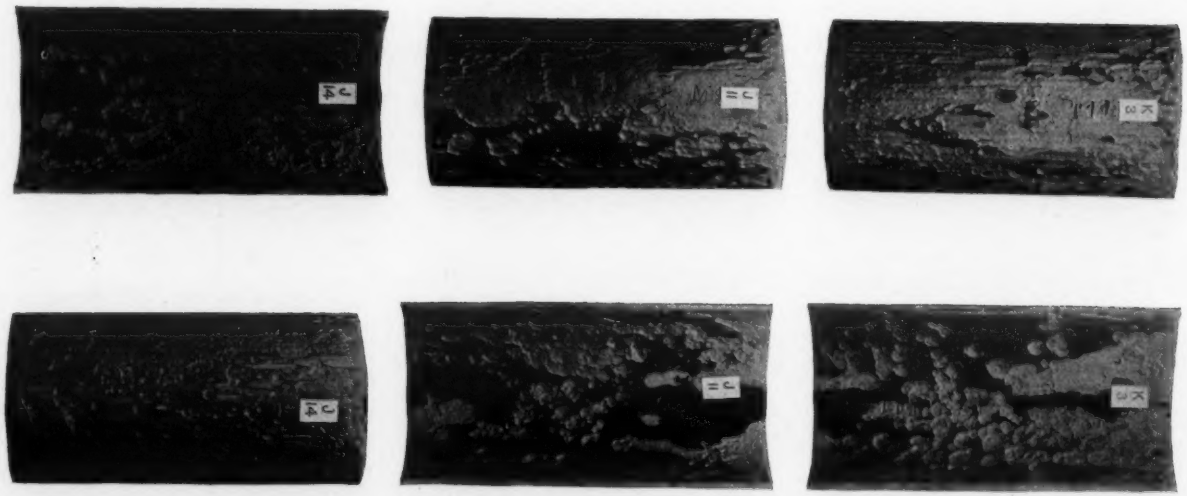


Plate I*a*.—Same Samples After Sixty-four Weeks.

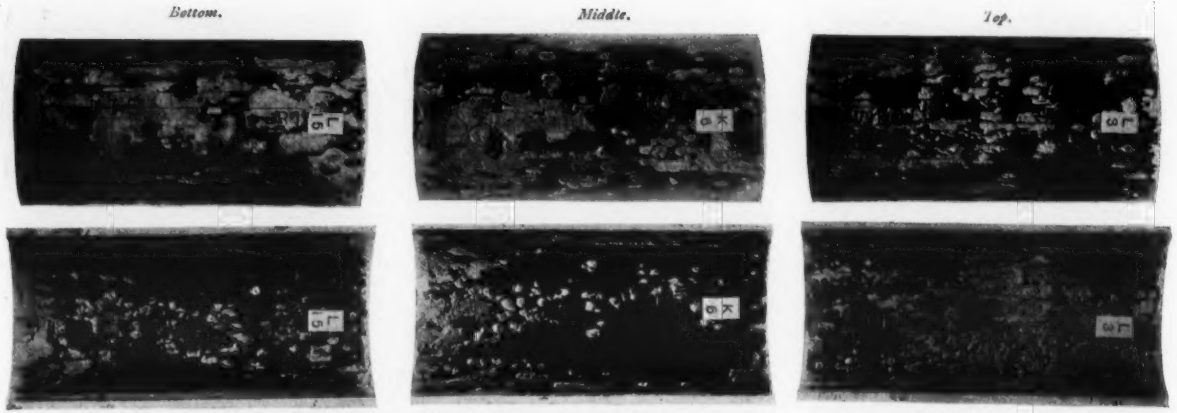



Plate II.—Hot-Drawn Seamless Steel Tubes, Showing Greatest Amount of Corrosion After Sixteen Weeks.

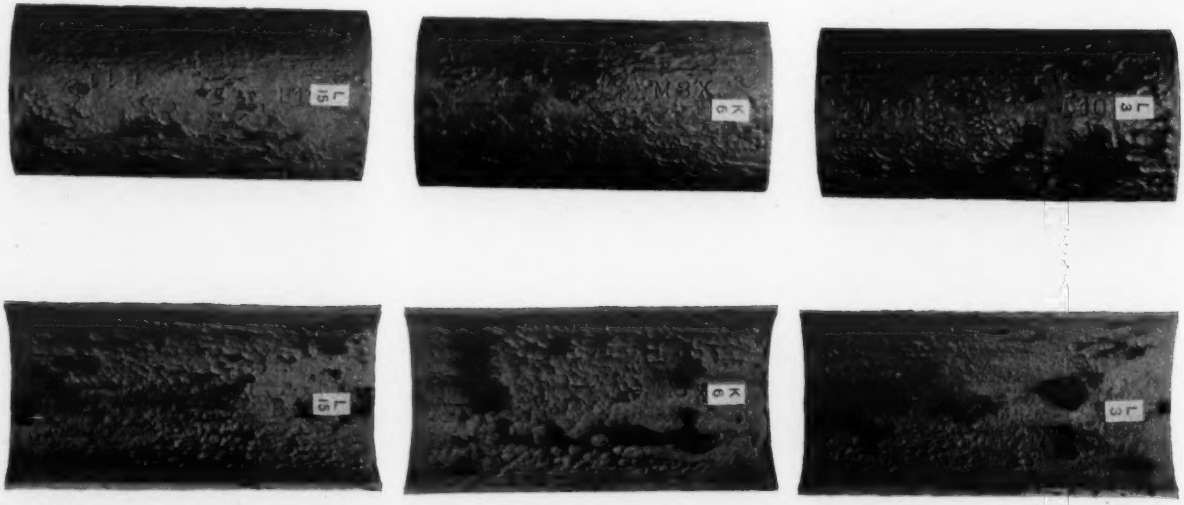


Plate II*a*.—Same Samples After Sixty-four Weeks.

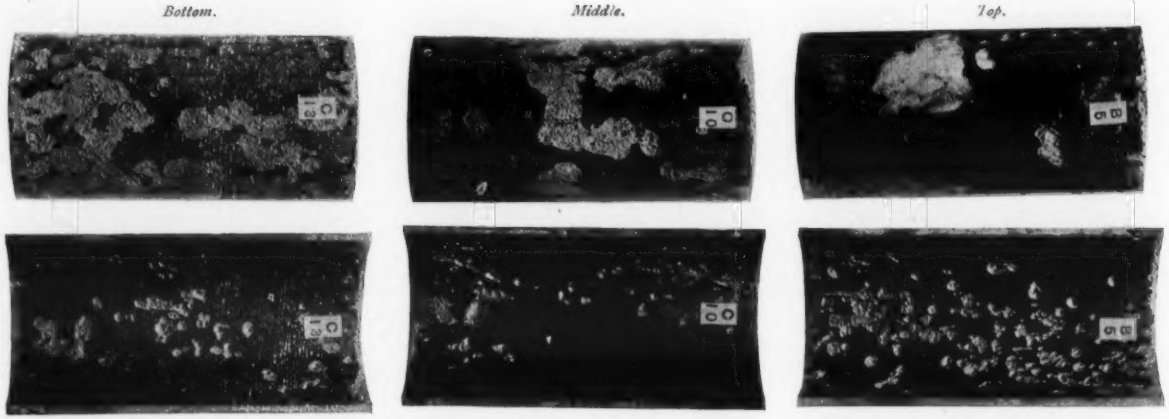



Plate III.—Lap-Welded Bessemer Steel Tubes, Showing Least Amount of Corrosion After Sixteen Weeks.

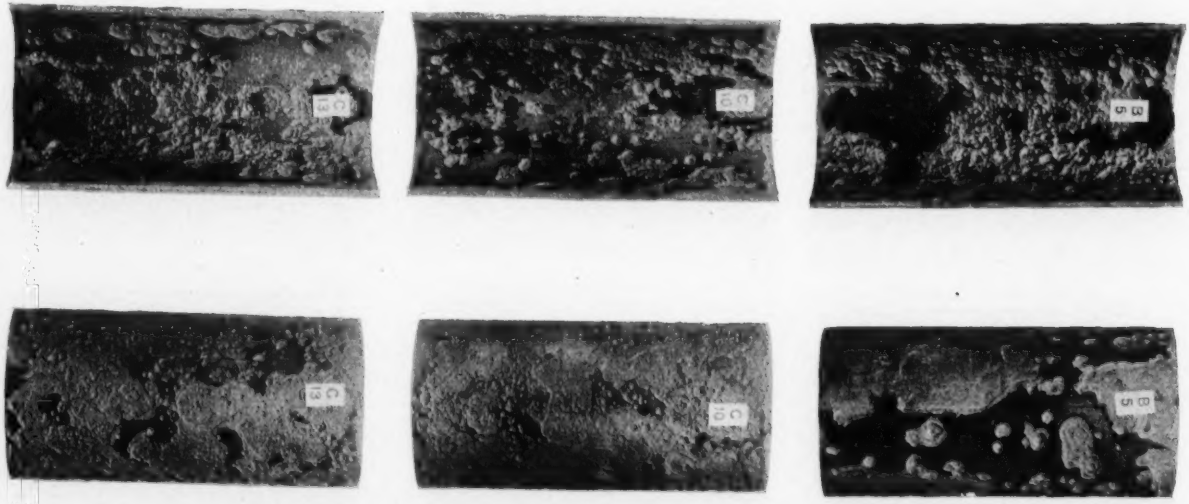


Plate III*a*.—Same Samples After Sixty-four Weeks.

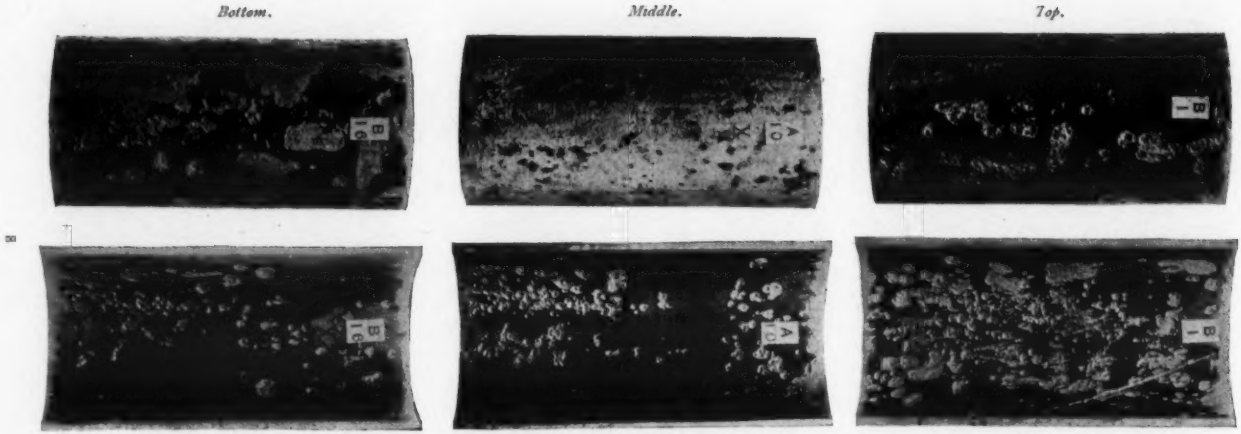



Plate IV.—Lap-Welded Bessemer Steel Tubes, Showing Greatest Amount of Corrosion After Sixteen Weeks.

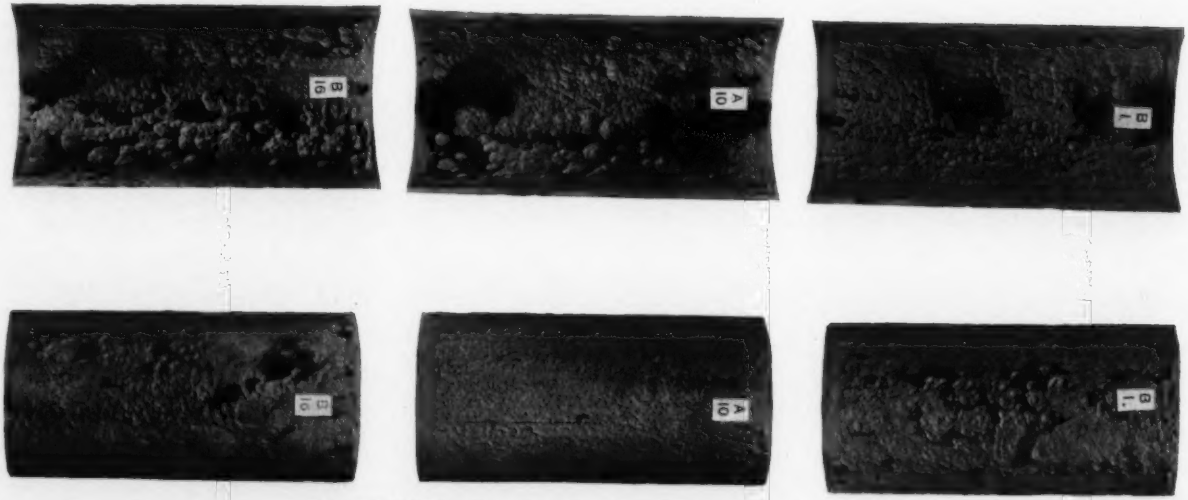



Plate IV*a*.—Same Samples After Sixty-four Weeks.

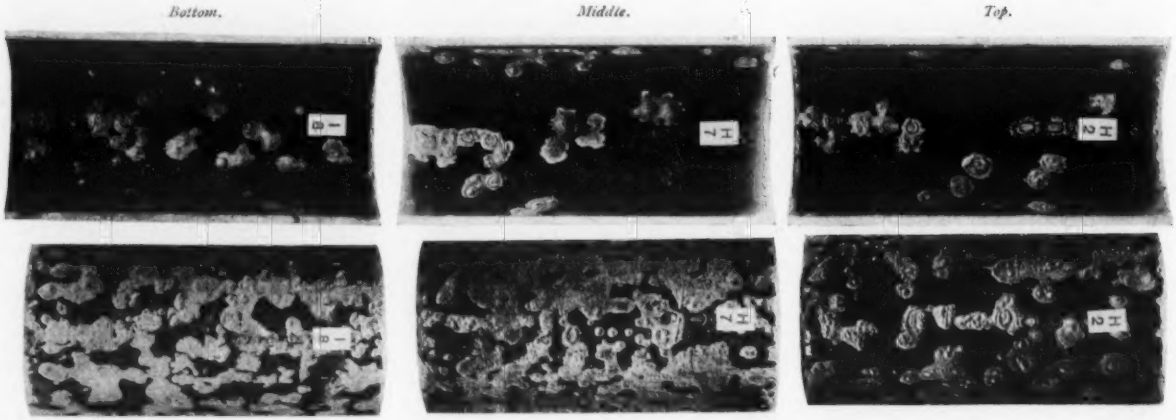



Plate V.—Cold-Drawn Seamless Steel Tubes, Showing Least Amount of Corrosion After Sixteen Weeks.

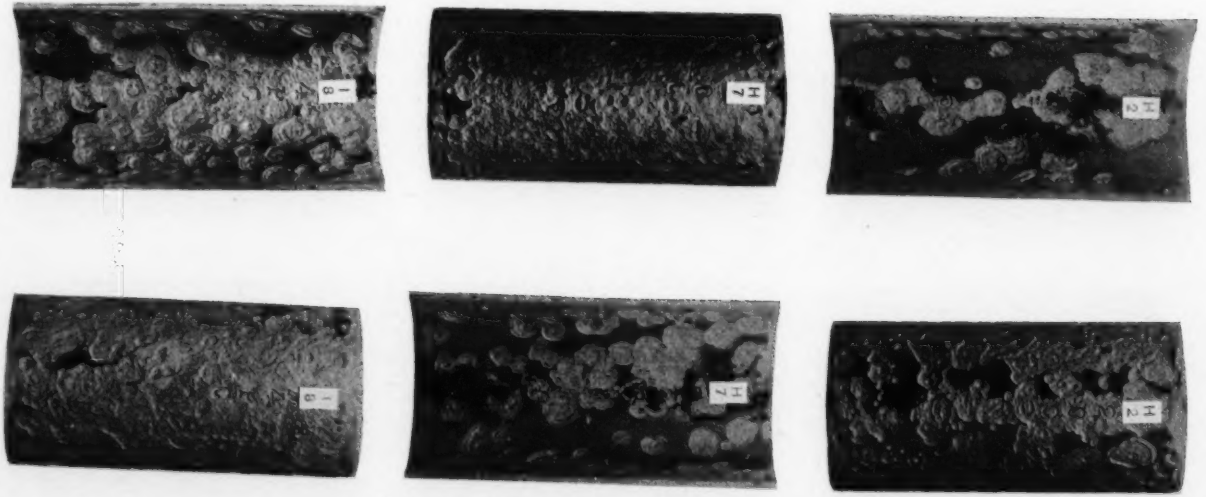


Plate V*a*.—Same Samples after Sixty-four Weeks.

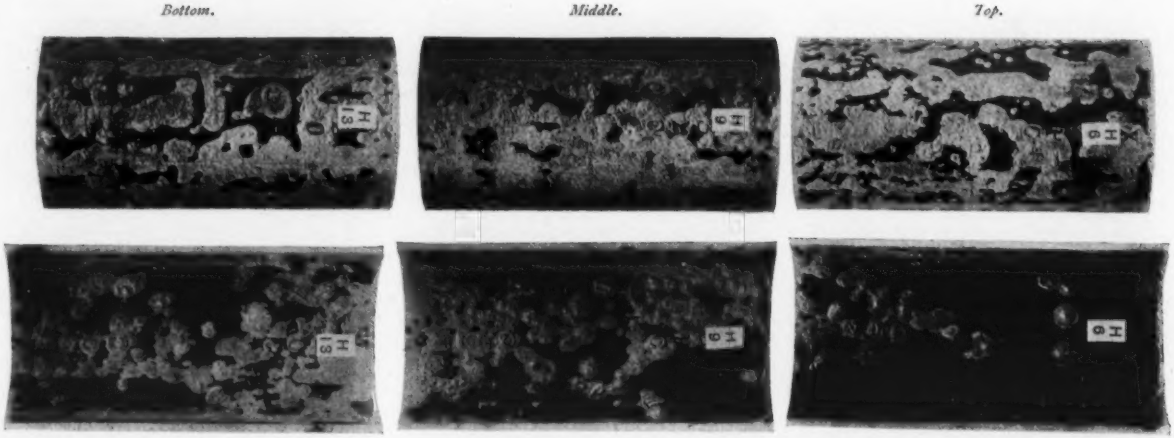



Plate VI.—Cold-Drawn Seamless Steel Tubes, Showing Greatest Amount of Corrosion After Sixteen Weeks.

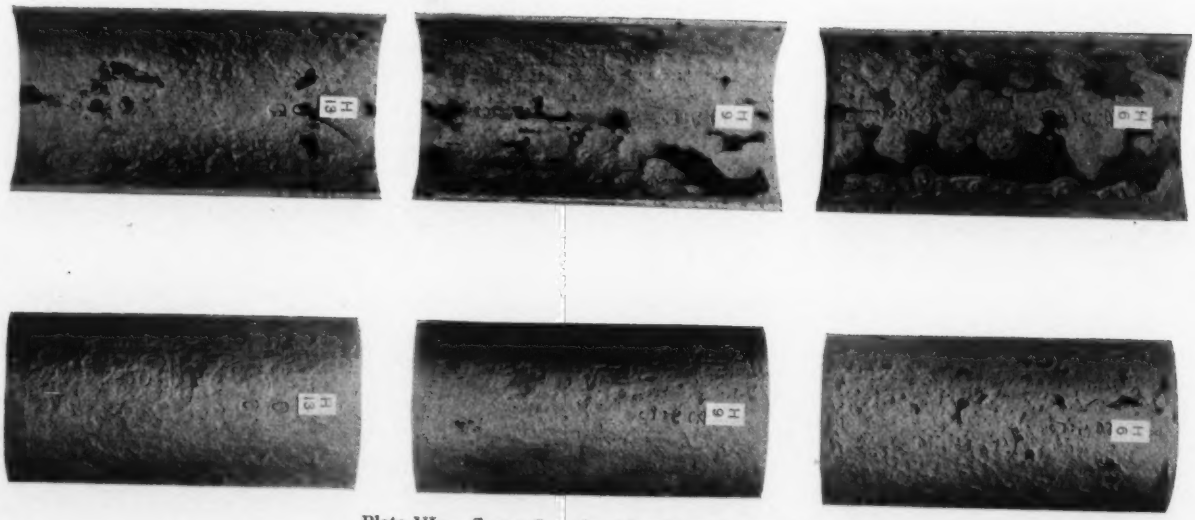


Plate VI*a*.—Sames Samples After Sixty-four Weeks.

*Least.* *Greatest.*

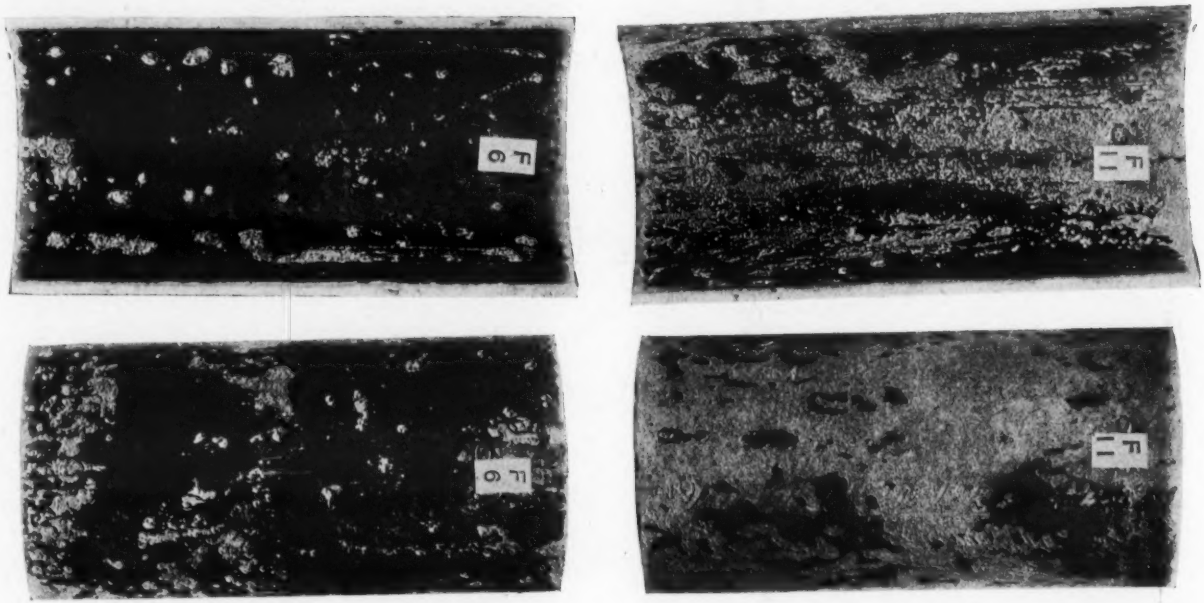



Plate VII.—Charcoal-Iron Tubes, Showing Least and Greatest Amounts of Corrosion After Sixteen Weeks.

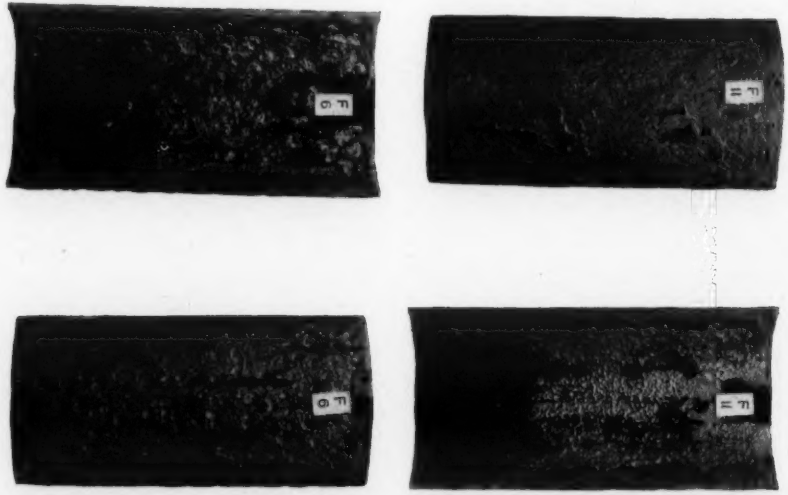


Plate VII*a*.—Same Samples After Sixty-four Weeks.

*Least Amount.* *Greatest Amount.*

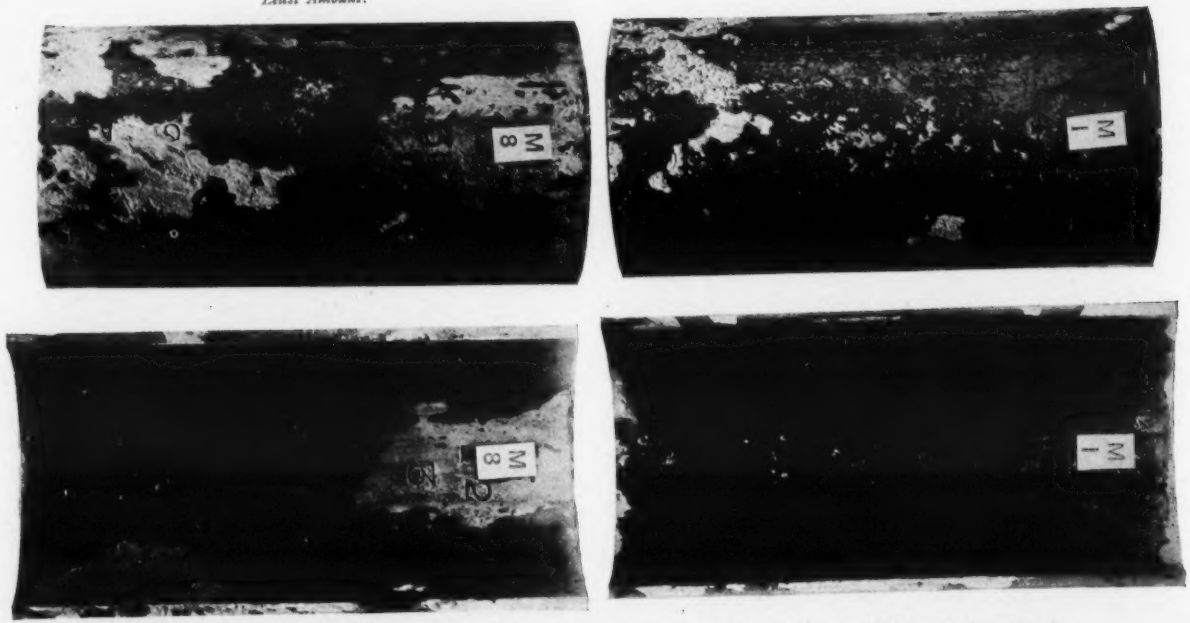



**Plate VIII.—Lap-Welded Bessemer Steel Tubes, Showing Corrosion in Alkaline Bath After Sixteen Weeks.**

# NO
# MA
# Y
# 4

XU

# Table Showing Loss in Weight of Samples of Steel and Iron after Four Periods

## THREE-INCH BOILER TUBES, No. 9 W. G. SE

| No. of sample. | Photo. number. | Total area, square inches. | Chemical analysis. C., per ct. | | P., per ct. | | S., per ct. | | M.,p.ct. | | Si., per ct. | | Ox., p. ct. | | Physical properties. Elastic limit. | Tensile strength. | Elongation, per ct. | Reduction of area, per cent. | After sixteen Original weight, grammes. | Weight after sixteen weeks, in bath, grammes. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N. T. Co. | Government. | N. T. Co. | Government. | N. T. Co. | Government. | N. T. Co. | Government. | N. T. Co. | Government. | N. T. Co. | Government. | | | | | | |
| T-1-Px ... | G-2.... | 54.767 | .17 | .12 | .024 | .035 | .047 | .048 | .57 | .56 | .005 | .005 | .23 | ... | 29,980 | 49,820 | 22.50 | 66.7 | 491 | 474 |
| T-1-Ox.. | G-4.... | 54 947 | .17 | .13 | .018 | .039 | .050 | .055 | .55 | .52 | .005 | .007 | .18 | ... | 26,650 | 49,760 | 23.13 | 71.3 | 509 | 489 |
| M-1-1x.. | G-10.. | 54.519 | .15 | .12 | .017 | .032 | .042 | .043 | .53 | .50 | .005 | Tr. | .20 | ... | 39,020 | 47,920 | 19.25 | 70.1 | 490 | 474 |
| M-2-P .... | G-11.. | 54.441 | .17 | 13 | .015 | .038 | .045 | .046 | .54 | .59 | .005 | .003 | .30 | ... | 38,450 | 55,640 | 16 63 | 62.7 | 489 | 468 |
| B-1-O..... | G-14 . | 54 432 | 13 | .11 | .006 | .028 | .036 | .031 | .44 | .48 | .005 | Tr. | .33 | ... | 26,830 | 46,400 | 24.13 | 68.6 | 496 | 482 |
| B-2-P .... | G-16.. | 54.428 | 13 | .11 | .012 | .031 | .033 | .035 | .43 | .56 | .005 | .002 | .25 | ... | 29,350 | 49,140 | 23.13 | 67.9 | 499 | 479 |
| T-2-Ox.... | H-2 ... | 55 201 | .18 | 13 | .022 | .038 | .049 | 051 | .52 | .52 | .005 | Tr. | .20 | ... | 27,290 | 47,520 | 18 | 72.8 | 505 | 480 |
| M-3-P..... | H-9 ... | 55.088 | .17 | .13 | .015 | .034 | .045 | .041 | .54 | .48 | .005 | .005 | .30 | ... | 25,680 | 48,860 | 26 88 | 66 2 | 507 | 485 |
| B-2-Px.... | H-12 .. | 54.996 | .13 | .17 | .012 | .031 | .033 | .035 | .43 | .56 | .005 | .002 | .25 | ... | 29,350 | 49,140 | 23.13 | 67.9 | 498 | 476 |
| B-2-Ox ... | H-14 . | 54.808 | .13 | .11 | .006 | .028 | .036 | .037 | .44 | .56 | .005 | Tr. | .33 | ... | 28,250 | 47,950 | 22.37 | 72.6 | 500 | 480 |
| T-3-Ox.... | I-1.... | 54.484 | .18 | .14 | .022 | .039 | .049 | .057 | .52 | .62 | .005 | Tr. | .30 | ... | 41,210 | 58,200 | 12 25 | 61.2 | 475 | 455 |
| T-4-Px .... | I-3.... | 54 752 | .17 | .12 | .024 | .032 | .057 | .049 | .55 | .58 | .005 | .004 | .25 | ... | 40,350 | 54,040 | 12.13 | 63 | 500 | 485 |
| M-3-1x.. | I-6.... | 53.878 | .15 | .09 | .014 | .033 | .047 | .044 | .46 | .64 | .005 | Tr. | .28 | ... | 37,900 | 60,000 | 13.13 | 67.6 | 467 | 453 |
| M-4-O .... | I-9.... | 54 951 | .16 | .09 | .019 | .033 | .049 | .046 | .47 | .56 | .005 | Tr. | .25 | ... | 36,830 | 52,680 | 13.50 | 70.2 | 527 | 510 |
| B-3-Ox .... | I-12.... | 53.425 | .13 | .10 | .006 | .031 | .038 | .040 | .48 | .55 | .005 | .003 | .25 | ... | 28,750 | 46,180 | 21.25 | 70 | 487 | 473 |
| B-4-O..... | I-15... | 55 373 | .13 | .10 | .005 | .027 | .033 | .043 | .46 | .54 | .005 | .002 | .28 | ... | 32,010 | 50,180 | 19.13 | 69.6 | 502 | 483 |
| THREE-INCH BOILER TUBES, No. 9 W. G. S | | | | | | | | | | | | | | | | | | | | |
| T-8 ..... | J-5 .... | 56.083 | .16 | .12 | .022 | .038 | .050 | .048 | .53 | .52 | .005 | .005 | .23 | ... | 43,100 | 59,260 | 21.50 | 68.1 | 582 | 566 |
| T-8x..... | J-6 .... | 53.613 | .16 | .12 | .022 | .038 | .050 | .048 | 53 | .52 | .005 | .005 | .23 | ... | 43,100 | 59,260 | 21.50 | 68.1 | 515 | 499 |
| M-7x..... | J-8 .... | 55.889 | .14 | .09 | .019 | .024 | .038 | .036 | .41 | .58 | .005 | .002 | .30 | ... | 41,340 | 54,560 | 20 | 66.5 | 543 | 523 |
| M-8 ..... | J-11 .. | 55.593 | .15 | .13 | .021 | .025 | .040 | .040 | .38 | .55 | .005 | .002 | .28 | ... | 35,550 | 52,400 | 23.63 | 68.1 | 461 | 452 |
| B-7 ..... | J-12 .. | 54.718 | .13 | .11 | .006 | .024 | .030 | .031 | 53 | .53 | .006 | Tr. | .24 | ... | 4,180 | 53,340 | 21.50 | 62 | 554 | 539 |
| B-7-D .... | J-14 .. | 56.490 | .12 | .11 | .012 | .025 | .031 | .032 | .48 | .53 | .005 | .003 | .38 | ... | 36,700 | 50,780 | 22.25 | 70.4 | 580 | 568 |
| T-11-D.... | K-3 .... | 54.370 | .15 | .13 | .024 | .025 | .047 | 049 | .52 | .58 | .005 | .002 | .32 | ... | 34,220 | 53,620 | 21.75 | 68.3 | 556 | 548 |
| T-9-D .... | K-5 .... | 55.894 | .14 | 13 | .022 | .030 | .051 | .044 | .52 | .54 | .005 | .005 | .30 | ... | 35,960 | 54,800 | 26.13 | 64.3 | 537 | 516 |
| M-8x..... | K-6 .... | 56.090 | 15 | .13 | .021 | .035 | .040 | .040 | .38 | .55 | .005 | .002 | .28 | ... | 35,550 | 52,400 | 23.63 | 68.1 | 553 | 531 |
| M-8-D.... | K-7 .... | 55 277 | .15 | .12 | .015 | .028 | .039 | .039 | .43 | .61 | .005 | Tr. | .37 | ... | 34,920 | 53,100 | 23.38 | 69.7 | 551 | 534 |
| B-8-D .... | K-13. | 53.725 | .13 | .10 | .012 | .021 | .033 | .027 | .51 | .60 | .005 | Tr. | .30 | ... | 36,670 | 50,060 | 27.25 | 71 9 | 536 | 523 |
| B-9 ..... | K-15. | 55.657 | .13 | .10 | .006 | .024 | .034 | .033 | .53 | .58 | .005 | Tr. | .32 | ... | 37,950 | 51,240 | 22.25 | 64.6 | 554 | 535 |
| T-10 ..... | L-2 .... | 55.847 | .15 | .14 | .026 | .032 | .043 | .047 | .54 | .55 | .005 | .005 | .27 | ... | 37,510 | 53,840 | 21.75 | 68.1 | 457 | 440 |
| T-10x..... | L-3 .... | 55 780 | .15 | .14 | .026 | .032 | .043 | .047 | .54 | .55 | .005 | .005 | .27 | ... | 37,510 | 53,840 | 21.75 | 68 1 | 597 | 574 |
| M-10-D... | L-9 .... | 56.060 | .13 | .17 | .005 | .027 | .040 | .039 | .55 | .62 | .005 | Tr. | .33 | ... | 35,300 | 53,400 | 21 | 70.3 | 570 | 551 |
| M-10-Dx. | L-10 .. | 54.372 | .13 | .12 | .005 | .027 | .040 | .039 | .55 | .62 | .005 | Tr. | .33 | ... | 35,300 | 53,400 | 21 | 70.3 | 504 | 484 |
| B-10-D .... | L-13.. | 57.596 | .12 | .09 | .011 | .020 | .030 | .026 | .51 | .58 | .005 | Tr. | .29 | ... | 33,380 | 49,450 | 23.13 | 74.5 | 524 | 508 |
| B-11-D .... | L-16.. | 56.662 | .12 | .09 | .011 | .021 | .032 | .025 | .49 | .60 | .005 | Tr. | .36 | ... | 31,230 | 49,130 | 22.50 | 70.1 | 542 | 524 |
| THREE-INCH BOILER TUBES, No. 9 W. G | | | | | | | | | | | | | | | | | | | | |
| 4x..... | D-4 .... | 55.030 | Tr. | .02 | .032 | .040 | .011 | .004 | Tr. | .05 | .030 | .014 | .108 | ... | 26,920 | 44,750 | 24 | 55.7 | 495 | 476 |
| 14..... | D-15. | 54.650 | Tr. | .02 | .032 | .040 | .011 | .004 | Tr. | .06 | .026 | .009 | .110 | ... | 24,800 | 43,500 | 27.35 | 56 | 517 | 503 |
| 18..... | E-3 .... | 54.105 | Tr. | .02 | .030 | .041 | .012 | .007 | Tr. | .03 | .021 | .025 | .120 | ... | 27,180 | 46,480 | 26 63 | 65 8 | 502 | 478 |
| 20..... | E-7 .... | 54.604 | Tr. | .02 | .068 | .044 | .020 | .018 | Tr | .05 | .019 | .015 | .102 | ... | 28,131 | 49,510 | 22.63 | 47.8 | 505 | 498 |
| 30x..... | F-6 .... | 54.590 | Tr. | .02 | .034 | .038 | .012 | .010 | Tr. | .02 | .027 | .030 | .128 | ... | 24,450 | 43,250 | 25.63 | 59.8 | 488 | 475 |
| 33..... | F-11 .. | 54.841 | Tr. | .02 | .036 | .050 | .014 | .013 | Tr. | .07 | .025 | .005 | .112 | ... | 27,570 | 47,510 | 26.25 | 58 | 515 | 487 |
| THREE-INCH BOILER TUBES, No. 9 W. G. LAP | | | | | | | | | | | | | | | | | | | | |
| 1-1x..... | A-2 .... | 54.240 | .065 | .09 | .115 | .120 | .081 | .093 | .31 | .29 | ... | Tr. | .35 | ... | 39,450 | 60,980 | 20.63 | 51.1 | 460 | 439 |
| 1-3x..... | A-6.... | 55.081 | .065 | .09 | .112 | .118 | .077 | .084 | .29 | 29 | .0 6 | Tr. | .40 | ... | 38,020 | 58,480 | 20 38 | 51.2 | 489 | 470 |
| 7-2x ..... | A-10... | 54.843 | .065 | .09 | .111 | .120 | .081 | .086 | .34 | .32 | .066 | .003 | .25 | ... | 37,590 | 58,960 | 20.63 | 58 | 508 | 488 |
| 7-3..... | A-11.. | 54 753 | .060 | .09 | .109 | .114 | .084 | .092 | .49 | .29 | .006 | Tr. | .25 | ... | 37,060 | 60,980 | 20.38 | 50.2 | 503 | 488 |
| 13-1x.... | A-13.. | 53 510 | .060 | .09 | .107 | .105 | .078 | .079 | .31 | .32 | .102 | .002 | .36 | ... | 37,700 | 59,900 | 20.50 | 59.6 | 511 | 498 |
| 13-2x.... | A-15.. | 55.407 | .070 | .09 | .107 | .105 | .078 | .081 | .29 | .32 | .010 | .003 | .26 | ... | 37,780 | 58,980 | 17.38 | 58 9 | 513 | 496 |
| 2-1..... | B-1.... | 55 141 | .065 | .09 | .120 | .120 | .094 | .095 | .32 | .30 | .0C6 | .004 | .28 | ... | 47,380 | 61,700 | 19 38 | 53.7 | 514 | 490 |
| 2-3..... | B-5.... | 55.128 | .070 | .09 | .114 | .122 | .089 | .090 | .31 | 30 | .006 | Tr. | .23 | ... | 40,930 | 62,420 | 22.50 | 51.7 | 512 | 494 |
| 8-3..... | B-8.... | 54 651 | .060 | .09 | .114 | .101 | .081 | 045 | .31 | .30 | .013 | .004 | .34 | ... | 38,460 | 56,920 | 22 50 | 61.1 | 511 | 493 |
| 8-4..... | B-10 . | 54 882 | .070 | .09 | .109 | .112 | .076 | .084 | .28 | .30 | .006 | Tr. | .21 | ... | 37,710 | 60,500 | 20.63 | 62.1 | 518 | 504 |
| 13-4x.... | B-14.. | 52 856 | .060 | .09 | .105 | .105 | .077 | .079 | .28 | .35 | .006 | .001 | .30 | ... | 38,500 | 58,200 | 20 25 | 55.2 | 519 | 504 |
| 14-1x.... | B-16.. | 54.392 | .060 | .09 | .104 | .103 | .075 | .081 | .32 | .36 | .010 | .003 | .33 | ... | 38,860 | 59,240 | 20 | 51 3 | 497 | 479 |
| 3-1..... | C-2.... | 53 702 | .065 | .09 | .109 | .110 | .076 | .081 | .34 | .28 | .006 | Tr. | .30 | ... | 36,600 | 58,080 | 18 13 | 58.2 | 507 | 487 |
| 3-1x..... | C-3.... | 54.905 | .065 | .09 | .109 | .110 | .076 | 081 | .34 | .28 | .006 | Tr. | .30 | ... | 36,600 | 58,080 | 18.13 | 58 2 | 536 | 517 |
| 9-1..... | C-6.... | 54.229 | .065 | .09 | .110 | .110 | .080 | .082 | .29 | .27 | .006 | Tr. | .21 | ... | 37,130 | 58,960 | 17 63 | 57.1 | 496 | 479 |
| 12-1..... | C-9.... | 53.831 | .070 | .09 | .106 | .106 | .074 | .089 | 30 | .31 | .006 | .003 | .20 | ... | 38,740 | 60,320 | 22.88 | 58 4 | 510 | 497 |
| 14-2x.... | C-12.. | 53.285 | .060 | .09 | .097 | .106 | .079 | .080 | .30 | 34 | 015 | Tr. | .34 | ... | 36,810 | 58,460 | 17 | 56.1 | 495 | 479 |
| 14-4x.... | C-16.. | 54.144 | .060 | .10 | .107 | .113 | .077 | 077 | 31 | .32 | 0C9 | .002 | .21 | ... | 37,750 | 59,900 | 18.75 | 54.7 | 513 | 501 |

## Four Periods of Sixteen Weeks Each, Exposure to Air and Distilled Water.

### No. 9 W. G. SEAMLESS COLD-DRAWN.

| per cent. | After sixteen weeks. | | | | After thirty-two weeks. | | | | After forty-eight weeks. | | | | After sixty-four weeks. | | | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Original weight, grammes. | Weight after sixteen weeks, in bath, grammes. | Loss in grammes. | Loss per sq. inch, area, in grammes. | Weight at beginning of test, grammes. | Weight after second sixteen weeks, in bath, grammes. | Loss in grammes. | Loss per sq. inch, area, in grammes. | Weight at beginning of test, grammes. | Weight after third sixteen weeks, in bath, grammes. | Loss in grammes. | Loss per sq. inch, area, in grammes. | Weight at beginning of test, grammes. | Weight after fourth sixteen weeks, in bath, grammes. | Loss in grammes. | Loss per sq. inch, area, in grammes. | |
| .7 | 491 | 474 | 17 | .3104 | 474 | 438 | 36 | .6573 | 438 | 412 | 26 | .4747 | 412 | 379 | 33 | .6026 | Top of ingot. |
| .3 | 509 | 489 | 20 | .3640 | 489 | 455 | 34 | .6188 | 455 | 429 | 26 | .4732 | 429 | 395 | 34 | .6188 | Top of ingot. |
| .1 | 490 | 474 | 16 | .2935 | 474 | 447 | 27 | .4952 | 447 | 425 | 22 | .4035 | 425 | 404 | 21 | .3852 | Middle of ingot. |
| .7 | 489 | 468 | 21 | .3858 | 468 | 433 | 35 | .6429 | 433 | 404 | 29 | .5327 | 404 | 376 | 28 | .5143 | Middle of ingot. |
| .6 | 496 | 482 | 14 | .2572 | 482 | 455 | 27 | .4960 | 455 | 432 | 23 | .4225 | 432 | 407 | 25 | .4593 | Bottom of ingot. |
| .9 | 499 | 479 | 20 | .3675 | 479 | 445 | 34 | .6247 | 445 | 416 | 29 | .5328 | 416 | 384 | 32 | .5879 | Bottom of ingot. |
| .8 | 505 | 490 | 15 | .2717 | 490 | 462 | 28 | .5072 | 462 | 442 | 20 | .3623 | 442 | 415 | 27 | .4891 | Top of ingot, least. |
| 2 | 507 | 485 | 22 | .3993 | 485 | 449 | 36 | .6535 | 449 | 422 | 27 | .4901 | 422 | 393 | 29 | .5264 | Middle of ingot, greatest. |
| .9 | 498 | 476 | 22 | .4000 | 476 | 438 | 38 | 6010 | 438 | 410 | 28 | .5091 | 410 | 380 | 30 | .5455 | Bottom of ingot, greatest. |
| .6 | 500 | 480 | 20 | .3649 | 480 | 443 | 37 | .6751 | 443 | 415 | 28 | .5109 | 415 | 389 | 26 | .4744 | Bottom of ingot, least. |
| .2 | 475 | 455 | 20 | .3671 | 455 | 420 | 35 | 6424 | 420 | 392 | 28 | .5139 | 392 | 365 | 27 | .4956 | Top of ingot. |
| | 500 | 485 | 15 | .2739 | 485 | 455 | 30 | .5479 | 455 | 430 | 25 | .4566 | 430 | 403 | 27 | 4931 | Top of ingot. |
| .6 | 467 | 453 | 14 | .2599 | 453 | 429 | 24 | .4455 | 429 | 409 | 20 | .3712 | 409 | 386 | 23 | .4267 | Middle of ingot. |
| .2 | 527 | 510 | 17 | .3090 | 510 | 481 | 29 | .5277 | 481 | 455 | 26 | .4731 | 455 | 429 | 26 | .4731 | Middle of ingot. |
| | 487 | 473 | 14 | .2621 | 473 | 446 | 27 | .5054 | 446 | 427 | 19 | .3556 | 427 | 399 | 28 | .5241 | Bottom of ingot. |
| .6 | 502 | 483 | 19 | .3431 | 483 | 448 | 35 | .6320 | 448 | 422 | 26 | .4695 | 422 | 394 | 28 | .5057 | Bottom of ingot. |
| , No. 9 W. G. SEAMLESS HOT-DRAWN. | | | | | | | | | | | | | | | | | |
| .1 | 582 | 566 | 16 | .3853 | 566 | 538 | 28 | .4993 | 538 | 520 | 18 | .3210 | 520 | 490 | 30 | .5331 | Top of ingot. |
| .1 | 515 | 499 | 16 | .2985 | 499 | 469 | 30 | .5596 | 469 | 450 | 19 | .3544 | 450 | 422 | 28 | .5223 | Top of ingot. |
| .5 | 543 | 523 | 20 | .3578 | 523 | 489 | 34 | .6083 | 489 | 469 | 20 | .3578 | 469 | 438 | 31 | .5546 | Middle of ingot. |
| .1 | 461 | 452 | 9 | .1618 | 452 | 426 | 26 | .4677 | 426 | 411 | 15 | .2698 | 411 | 384 | 27 | .4856 | Middle of ingot. |
| | 554 | 539 | 15 | .2742 | 539 | 512 | 27 | .4934 | 512 | 496 | 16 | .2924 | 496 | 467 | 29 | .5299 | Bottom of ingot. |
| .4 | 580 | 568 | 12 | .2124 | 568 | 539 | 29 | .5133 | 539 | 521 | 18 | .3186 | 521 | 495 | 26 | 4602 | Bottom of ingot. |
| .3 | 556 | 548 | 8 | .1471 | 548 | 516 | 32 | .5885 | 516 | 497 | 19 | .3494 | 497 | 469 | 28 | .5149 | Top of ingot. |
| .3 | 537 | 516 | 21 | .3757 | 516 | 485 | 31 | .5546 | 485 | 464 | 21 | .3757 | 464 | 434 | 30 | .5367 | Top of ingot. |
| .1 | 553 | 531 | 22 | .3922 | 531 | 496 | 35 | .6239 | 496 | 474 | 22 | .3922 | 474 | 442 | 32 | .5751 | Middle of ingot. |
| .7 | 551 | 534 | 17 | .3075 | 534 | 500 | 34 | .6150 | 500 | 477 | 23 | .4165 | 477 | 447 | 30 | .5427 | Middle of ingot. |
| .9 | 536 | 523 | 13 | .2420 | 523 | 496 | 27 | .5025 | 496 | 476 | 20 | .3702 | 476 | 447 | 29 | .5398 | Bottom of ingot. |
| .6 | 554 | 535 | 19 | .3413 | 535 | 507 | 28 | .5030 | 507 | 489 | 18 | .3234 | 489 | 462 | 27 | .4851 | Bottom of ingot. |
| .1 | 457 | 440 | 17 | .3043 | 440 | 408 | 32 | .5729 | 408 | 386 | 22 | .3939 | 386 | 357 | 29 | .5192 | Top of ingot. |
| 1 | 597 | 574 | 23 | .4123 | 574 | 538 | 36 | .6453 | 538 | 514 | 24 | .4302 | 514 | 486 | 28 | .5019 | Top of ingot. |
| .3 | 570 | 551 | 16 | .2854 | 551 | 528 | 23 | .4102 | 528 | 508 | 20 | .3567 | 508 | 485 | 23 | .4102 | Middle of ingot. |
| .3 | 504 | 484 | 20 | .3679 | 484 | 458 | 26 | .4782 | 458 | 439 | 19 | .3494 | 439 | 412 | 27 | .4965 | Middle of ingot. |
| .5 | 524 | 508 | 16 | .2778 | 508 | 484 | 24 | .4167 | 484 | 467 | 17 | .2951 | 467 | 443 | 24 | .4167 | Bottom of ingot. |
| .1 | 542 | 524 | 18 | .3177 | 524 | 493 | 31 | .5471 | 493 | 473 | 20 | .3529 | 473 | 444 | 29 | .5118 | Bottom of ingot. |
| BES, No. 9 W. G. LAP-WELD IRON. | | | | | | | | | | | | | | | | | |
| .7 | 495 | 476 | 19 | 3451 | 476 | 444 | 32 | .5815 | 444 | 423 | 21 | .3816 | 423 | 395 | 28 | .5088 | ..... |
| | 517 | 503 | 14 | 2562 | 503 | 470 | 33 | .6038 | 470 | 450 | 20 | .3659 | 450 | 420 | 30 | .5489 | ..... |
| 8 | 502 | 478 | 24 | 4436 | 478 | 443 | 35 | .6468 | 443 | 418 | 25 | .4620 | 418 | 384 | 34 | .6284 | ..... |
| .8 | 505 | 498 | 13 | .2248 | 498 | 473 | 25 | .4630 | 473 | 455 | 18 | .3296 | 455 | 430 | 25 | .4560 | ..... |
| .8 | 488 | 475 | 13 | .2248 | 475 | 442 | 33 | .6045 | 442 | 420 | 22 | .4030 | 420 | 400 | 20 | .3563 | ..... |
| | 515 | 487 | 28 | 5012 | 487 | 452 | 35 | .6364 | 452 | 428 | 24 | .4376 | 428 | 404 | 24 | .4376 | ..... |
| No. 9 W. G. LAP-WELD BESSEMER STEEL. | | | | | | | | | | | | | | | | | |
| .1 | 460 | 439 | 21 | .3872 | 439 | 410 | 29 | .5346 | 410 | 384 | 26 | .4793 | 384 | 356 | 28 | .5162 | Top of ingot. |
| .2 | 489 | 470 | 19 | 3449 | 470 | 441 | 29 | .5264 | 441 | 414 | 27 | .4901 | 414 | 386 | 28 | .5083 | Top of ingot. |
| | 508 | 488 | 20 | .3647 | 488 | 459 | 29 | .5287 | 459 | 436 | 23 | .4194 | 436 | 411 | 25 | .4558 | Middle of ingot. |
| .2 | 503 | 488 | 15 | .2739 | 488 | 460 | 28 | .5114 | 460 | 435 | 25 | .4566 | 435 | 408 | 27 | .4931 | Middle of ingot. |
| .6 | 511 | 498 | 13 | .2430 | 498 | 473 | 25 | .4672 | 473 | 450 | 23 | .4298 | 450 | 422 | 28 | .5045 | Bottom of ingot. |
| 9 | 513 | 496 | 17 | .3068 | 496 | 468 | 28 | .5053 | 468 | 445 | 23 | .4151 | 445 | 417 | 28 | .5053 | Bottom of ingot. |
| .7 | 514 | 490 | 24 | .4352 | 490 | 457 | 31 | .5984 | 457 | 434 | 23 | .4171 | 434 | 406 | 28 | .5077 | Top of ingot. |
| .7 | 512 | 494 | 18 | .3262 | 494 | 462 | 32 | .5799 | 462 | 442 | 20 | .3624 | 442 | 416 | 26 | 4711 | Top of ingot. |
| .1 | 511 | 493 | 18 | .3294 | 493 | 461 | 32 | .5855 | 461 | 436 | 25 | 4572 | 436 | 408 | 28 | .5123 | Middle of ingot. |
| .1 | 518 | 504 | 14 | .2551 | 504 | 480 | 24 | .4373 | 480 | 459 | 21 | .3826 | 459 | 435 | 24 | .4373 | Middle of ingot. |
| .2 | 519 | 504 | 15 | .2857 | 504 | 478 | 26 | .4919 | 478 | 456 | 22 | .4162 | 456 | 427 | 29 | .5486 | Bottom of ingot. |
| 3 | 497 | 479 | 18 | .3310 | 479 | 448 | 31 | .5699 | 448 | 425 | 23 | .4228 | 425 | 397 | 28 | .5147 | Bottom of ingot. |
| .2 | 507 | 487 | 20 | .3724 | 487 | 460 | 27 | .5026 | 460 | 440 | 20 | .3724 | 440 | 412 | 28 | .5214 | Top of ingot. |
| 2 | 536 | 517 | 19 | .3460 | 517 | 494 | 23 | .4189 | 494 | 475 | 19 | .3460 | 475 | 450 | 25 | .4553 | Top of ingot. |
| .1 | 496 | 479 | 17 | .3135 | 479 | 454 | 25 | 4610 | 454 | 436 | 18 | .3319 | 436 | 406 | 30 | .5532 | Middle of ingot. |
| 4 | 510 | 497 | 13 | .2281 | 497 | 477 | 20 | .3715 | 477 | 460 | 17 | .3158 | 460 | 434 | 26 | .4829 | Middle of ingot. |
| .1 | 495 | 479 | 16 | .3004 | 479 | 455 | 24 | .4504 | 455 | 434 | 21 | .3941 | 434 | 406 | 28 | .5254 | Bottom of ingot. |
| .7 | 513 | 501 | 12 | .2216 | 501 | 481 | 20 | .3693 | 481 | 461 | 20 | .3693 | 461 | 440 | 21 | .3878 | Bottom of ingot. |

the regular tests were being carried on. As some of the water, lost through evaporation and handling the samples, had to be replaced, there was probably a gradual decrease in the degree of alkalinity of water in the tank during the trial.

*Results.*—After tabulating the results obtained from the different samples a general average of the losses per square inch of surface area of each class of tube was made.

Those averages, for each period of sixteen weeks, were as follows:

*Average Loss in Grammes.*

| Class of tube. | After 16 weeks. (1st 16 weeks.) | After 32 weeks. (2d 16 weeks.) | After 48 weeks. (3d 16 weeks.) | After 64 weeks. (4th 16 weeks.) |
|---|---|---|---|---|
| (1) Hot-drawn seamless steel, . . | .3034 | .5333 | .3510 | .5070 |
| (2) Lap-welded Bessemer steel, . . | .3147 | .4950 | .4043 | .4945 |
| (3) Cold-drawn seamless steel, . . | .3268 | .5795 | .4595 | .5076 |
| (4) Charcoal iron, . . . . . | .3326 | .5896 | .3966 | .4893 |

The difference in the amount of loss in the four classes of tubes is not great, that of the charcoal-iron tubes, which had the greatest loss, being, roughly, 6.3 per cent. more than the loss of the hot-drawn seamless tubes, which suffered the least.

Considering the three grades of the hot-drawn seamless tubes alone, it was found that the average losses per square inch of surface area were:

| | After 16 weeks. (1st 16 weeks.) | After 32 weeks. (2d 16 weeks.) | After 48 weeks. (3d 16 weeks.) | After 64 weeks. (4th 16 weeks.) |
|---|---|---|---|---|
| Tubes from the top of ingot, . . . | .3205 | .5700 | .3708 | .5213 |
| Tubes from the middle of ingot, . | .3121 | .5339 | .3571 | .5108 |
| Tubes from the bottom of ingot, . | .2776 | .4960 | .3254 | .4906 |

The difference in the losses of these three grades is very marked. At the end of the first sixteen weeks those from the top of the ingot lost 15.4 per cent. more and those from the middle of the ingot 12.4 per cent. more than those from the bottom of the ingot. At the end of thirty-two weeks those from the top of the ingot lost 14.9 per cent. more and those from the middle of the ingot 7.6 per cent. more than those from the bottom of the ingot.

At the end of forty-eight weeks those from the top of the ingot lost 15.9 per cent. more and those from the middle of the ingot 9.7 per cent. more than those from the bottom of the ingot. At the end of sixty-four weeks those from the top of the ingot lost 6.2 per cent. more and those from the middle of the ingot 4.1 per cent. more than those from the bottom of the ingot. The loss from the bottom samples being less, probably on account of the lesser amount of impurities and greater density of the metal of the ingot in this part.

Of the three grades of lap-welded Bessemer tubes the average losses per square inch were:

| | After 16 weeks. (1st 16 weeks.) | After 32 weeks. (2d 16 weeks.) | After 48 weeks. (3d 16 weeks.) | After 64 weeks. (4th 16 weeks.) |
|---|---|---|---|---|
| Tubes from the top of ingot, . . . | .3686 | .5268 | .4112 | .4966 |
| Tubes from the middle of ingot, . | .2941 | .4826 | .3939 | .4891 |
| Tubes from the bottom of ingot, . | .2814 | .4756 | .4079 | .4977 |

The difference here is even more marked for the top of the ingot than in the case of the hot-drawn tubes. At the end of the first sixteen weeks those from the top of the ingot lost 30.98 per cent. more and those from the middle of the ingot 4.51 per cent. more than those from the bottom of the ingot. At the end of thirty-two weeks those from the top of the ingot lost 10.76 per cent. more and those from the middle of the ingot 1.47 per cent. more than those from the bottom of the ingot. At the end of forty-eight weeks those from the top of the ingot lost .8 per cent. more and those from the middle of the ingot 3.43 per cent. less than those from the bottom of the ingot. At the end of sixty-four weeks those from the top of the ingot lost .22 per cent. less and those from the middle of the ingot 1.72 per cent. less than those from the bottom of the ingot; the great variation in loss of these samples being due probably to a greater amount of impurities of the metal of the ingot in this heat.

When the results obtained from the cold-drawn seamless tubes are investigated, a similar result as in the former cases appears, except that the losses in each series of sixteen weeks is much smaller than in the other cases.

The losses per square inch of area were:

| | After 16 weeks. (1st 16 weeks.) | After 32 weeks. (2d 16 weeks.) | After 48 weeks. (3d 16 weeks.) | After 64 weeks. (4th 16 weeks.) |
|---|---|---|---|---|
| Tubes from the top of ingot, . . . | .3288 | .6166 | .4796 | .5525 |
| Tubes from the middle of ingot, . | .3120 | .5278 | .4451 | .4498 |
| Tubes from the bottom of ingot, . | .3075 | .5645 | .4451 | .5192 |

The difference in the losses of these three grades is quite marked; at the end of the first sixteen weeks those from the top of the ingot lost 6.9 per cent. more and those from the middle of the ingot 1.4 per cent. more than those from the bottom of the ingot; at the end of thirty-two weeks those from the top of the ingot lost 9.2 per cent. more and those from the middle of the ingot lost 6.49 per cent. less than those from the bottom of the ingot; at the end of forty-eight weeks those from the top of the ingot lost 7.7 per cent. more and those from the middle of the ingot were equal to those from the bottom of the ingot; at the end of sixty-four weeks those from the top of the ingot lost 6.4 per cent. more, while those from the middle of the ingot lost 13.3 per cent. less than those from the bottom of the ingot.

It appears at first glance that these tubes corroded more uniformly than the two former kinds, but an examination of the averages for the separate tanks shows that this is not the case in the individual tanks. The averages for the individual tanks, both for the lap-welded Bessemer and for the cold-drawn seamless tubes, show the same general results, as are shown by the general averages for the three tanks as to the relative losses of the tubes from the top, middle and bottom of the ingot.

No reasonable cause can be assigned for this variation from the results that were obtained in the cases of the hot-drawn seamless tubes, unless it may possibly be due to the hot-swedge rolling and cold drawing to which the metal is subjected. This working which the metal receives may have a greater tendency to reduce the metal of the ingot to a more uniform density throughout than the process of the lap-welded and seamless hot-drawn tubes.

In the additional tank to the water of which the KOH. was

added at the beginning of the experiments, the average loss for the eight samples, all lap-welded Bessemer steel, was only .0997 grammes per square inch at the end of the first period of sixteen weeks. As this tank contained samples from the top, middle and bottom of the ingot, and the conditions were, with the exception of the alkali, the same as in the other three tanks containing the lap-welded Bessemer steel tubes, the results obtained from it can be fairly compared with the average of these three tanks. The average loss of these tanks was .31500 grammes per square inch of specimen, so that the loss in the alkaline tank was only 31.6 per cent. of that with fresh water. This result indicates strongly the wisdom of keeping the water in boilers slightly alkaline at all times as a safeguard against deterioration from oxidation. While the result obtained would seem to indicate the advisability of using cold-drawn seamless tubes, looking at it from the point of loss by corrosion alone, yet in making the choice other points must be considered, as, for instance, not only the amount of corrosion but also the nature of the corrosion, whether spread over a large area or concentrated in pits. Some of the tubes showing a large loss may have this loss spread over a large amount of surface and only superficial, while others showing a small loss may have this loss concentrated in three or four pits, which would destroy the value of the tubes much more rapidly than in the other case.

As has been stated, owing to the limited number of billets from which the cold-drawn seamless tubes were made, it was necessary to take two samples from each tube, one from the open and one from the pointed ends. From an inspection of the full tables it is found that the corrosion undergone by the samples from the pointed ends varies from that of the open end samples by 6.4 per cent. more and 13.3 per cent. less, respectively.

In drawing the hot-drawn seamless tubes, some of the tubes were drawn twice in one direction and three times in the opposite direction, while the remainder of the tubes were passed five times in one direction only. The averages of these different methods of passing are given in an accompanying table, as are those of the foregoing paragraph. By an inspection of this table it is seen that the average corrosion of the samples

which were passed in only one direction exceeds that of those samples which were passed in both directions. These excesses are as follows: Tank J, 17.09 per cent.; tank K, 17.92 per cent.; tank L, 17.35 per cent.; the average of the excess is 17.66 per cent.

In the cases of those samples of lap-welded iron and lap-welded Bessemer steel tubes which include the weld, the appended table shows that the influence of the weld is very slight, the average difference in corrosion possibly due to the weld being in the first case 6.13 per cent. greater, and in the second, .246 per cent. less, a difference so slight that it is hardly necessary to take it into account.

*Three-inch Boiler Tubes, No. 9, B. W. G., Seamless Cold-Drawn.*

Average of losses, in grammes per square inch, of samples taken from open and pointed ends.

OPEN ENDS.

| | Tank G. | Tank H. | Tank I. | Tanks G, H, I. |
|---|---|---|---|---|
| 1st period, . . . | .3049 | .3183 | .3082 | .3104 |
| 2d period, . . . | .5367 | .5911 | .5506 | .5594 |
| 3d period, . . . | .4330 | .4366 | .4366 | .4354 |
| 4th period, . . . | .4877 | .4817 | .4850 | .4848 |
| Total, 4 periods, . | 1.7623 | 1.8277 | 1.7804 | 1.7900 |

POINTED ENDS.

| | Tank G. | Tank H. | Tank I. | Tanks G, H, I. |
|---|---|---|---|---|
| 1st period, . . . | .3545 | .3996 | .2739 | .3427 |
| 2d period, . . . | .6416 | .6272 | .5479 | .6055 |
| 3d period, . . . | .5134 | .4996 | .4566 | .4899 |
| 4th period, . . . | .5682 | .5359 | .4931 | .5324 |
| Total, 4 periods, | 2.0777 | 2.0623 | 1.7715 | 1.9705 |

*Three-inch Boiler Tubes, No. 9, B. W. G., Seamless Hot-Drawn.*

Average losses, in grammes per square inch, from tubes passed in one direction, and in opposite directions, through dies.

*Five passes in one direction.*

| | Tank J. | Tank K. | Tank L. | Tanks J, K, L. |
|---|---|---|---|---|
| 1st period, . . . | .2955 | .3667 | .3583 | .3402 |
| 2d period, . . . | .5256 | .5634 | .6091 | .5660 |
| 3d period, . . . | .3191 | .3578 | .4120 | .3629 |
| 4th period, . . . | .5251 | .5301 | .5105 | .5219 |
| Total, 4 periods, . | 1.6653 | 1.8180 | 1.8899 | 1.7910 |

*Two passes in one, three in opposite direction.*

| | Tank J. | Tank K. | Tank L. | Tanks J, K, L. |
|---|---|---|---|---|
| 1st period, . . . | .2124 | .2681 | .3122 | .2642 |
| 2d period, . . . | .5133 | .5651 | .4630 | .5138 |
| 3d period, . . . | .3186 | .3779 | .3385 | .3450 |
| 4th period, . . . | .4204 | .5335 | .4588 | .4709 |
| Total, 4 periods, . | 1.4647 | 1.7446 | 1.5725 | 1.5939 |

*Three-inch Boiler Tubes, No. 9, B. W. G., Lap-weld Iron.*

Average losses, in grammes per square inch, of samples with and without welds.

WITH WELDS.

| | Tank D. | Tank E. | Tank F. | Tanks D, E, F. |
|---|---|---|---|---|
| 1st period, . . . | .3451 | .4436 | .2248 | .3378 |
| 2d period, . . . | .5815 | .6468 | .6045 | .6109 |
| 3d period, . . . | .3816 | .4620 | .4030 | .4155 |
| 4th period, . . . | .5088 | .6284 | .3563 | .4978 |
| Total, 4 periods, . | 1.8170 | 2.1808 | 1.5886 | 1.8620 |

WITHOUT WELDS.

| | Tank D. | Tank E. | Tank F. | Tanks D, E, F. |
|---|---|---|---|---|
| 1st period, . . . | .2562 | .2248 | .5012 | .3274 |
| 2d period, . . . | .6038 | .4650 | .6364 | .5684 |
| 3d period, . . . | .3659 | .3296 | .4376 | .3777 |
| 4th period, . . . | .5489 | .4560 | .4376 | .4808 |
| Total, 4 periods, | 1.7748 | 1.4754 | 2.0128 | 1.7543 |

*Three-Inch Lap-Weld Bessemer Steel Tubes.*

WITH WELDS.

Loss in grammes per square inch.

| | Tank A. | Tank B. | Tank C. | Tanks A,B,C. |
|---|---|---|---|---|
| 1st period, . . . | .3293 | .3083 | .2893 | .3089 |
| 2d period, . . . | .5124 | .5309 | .4129 | .4854 |
| 3d period, . . . | .4467 | .4195 | .3698 | .4120 |
| 4th period, . . . | .4980 | .5316 | .4561 | .4952 |
| Total, 4 periods, . | 1.7864 | 1.7903 | 1.5281 | 1.7015 |

WITHOUT WELDS.

| | Tank A. | Tank B. | Tank C. | Tanks A,B,C. |
|---|---|---|---|---|
| 1st period, . . . | .2739 | .3364 | .3047 | .3050 |
| 2d period, . . . | .5114 | .5503 | .4450 | .5022 |
| 3d period, . . . | .4566 | .4048 | .3400 | .4004 |
| 4th period, . . . | .4931 | .4821 | .5191 | .4981 |
| Total, 4 periods, . | 1.7350 | 1.7736 | 1.6088 | 1.7057 |

*Recapitulation.*

SEAMLESS HOT-DRAWN.

*Average loss (Grammes) per square inch.*

| | Tank J. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . | .2817 | .3419 | .2598 | .2433 |
| 2d period, . . . | .5235 | .5294 | .5380 | .5033 |
| 3d period, . . . | .3190 | .3377 | .3138 | .3055 |
| 4th period, . . . | .5143 | .5277 | .5201 | .4950 |
| Total, 4 periods, . | 1.6385 | 1.7367 | 1.6317 | 1.5471 |
| | Tank K. | Top. | Middle. | Bottom. |
| 1st period, . . . | .3009 | .2614 | .3498 | .2916 |
| 2d period, . . . | .5645 | .5715 | .6194 | .5027 |
| 3d period, . . . | .3712 | .3625 | .4043 | .3468 |
| 4th period, . . . | .5323 | .5258 | .5589 | .5124 |
| Total, 4 periods, . | 1.7689 | 1.7212 | 1.9324 | 1.6535 |

| | Tank L. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . | .3275 | .3583 | .3266 | .2977 |
| 2d period, . . . | .5117 | .6091 | .4442 | .4819 |
| 3d period, . . . | .3630 | .4120 | .3530 | .3240 |
| 4th period, . . . | .4760 | .5105 | .4533 | .4642 |
| Total, 4 periods, . | 1.6782 | 1.8899 | 1.5771 | 1.5678 |

| | Tanks J. K. & L. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . | .3033 | .3205 | .3120 | .2775 |
| 2d period, . . . | .5332 | .5700 | .5339 | .4959 |
| 3d period, . . . | .3511 | .3707 | .3570 | .3254 |
| 4th period, . . . | .5075 | .5213 | .5107 | .4905 |
| Total, 4 periods, . | 1.6951 | 1.7825 | 1.7136 | 1.5893 |

*Average of Chemical Analyses.*

NATIONAL TUBE CO.

| Average of— | Car. | Phos. | Sul. | Man. | Si. | Ox. |
|---|---|---|---|---|---|---|
| Tops, . . . . . | .15 | .022 | .046 | .52 | .005 | .28 |
| Middles, . . . . . | .14 | .015 | .039 | .44 | .005 | .30 |
| Bottoms, . . . . . | .13 | .010 | .031 | .51 | .005 | .32 |
| All tubes, . . . . | .14 | .016 | .039 | .49 | .005 | .30 |

GOVERNMENT.

| Average of— | Car. | Phos. | Sul. | Man. | Si. | Ox. |
|---|---|---|---|---|---|---|
| Tops, . . . . . | .13 | .029 | .045 | .54 | .004 | — |
| Middles, . . . . . | .12 | .017 | .037 | .57 | .002 | — |
| Bottoms, . . . . . | .10 | .023 | .028 | .53 | .002 | — |
| All tubes, . . . . | .12 | .023 | .037 | .55 | .003 | — |

*Recapitulation.*

LAP-WELD BESSEMER STEEL.

*Average Loss (Grammes) per Square Inch.*

| | Tank A. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . | .3201 | .3661 | .3193 | .2749 |
| 2d period, . . . | .5122 | .5305 | .5200 | .4862 |
| 3d period, . . . | .4483 | .4847 | .4380 | .4224 |
| 4th period, . . . | .4971 | .5122 | .4743 | .5049 |
| Total, 4 periods, . | 1.7777 | 1.8935 | 1.7516 | 1.6884 |

| | Tank B. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . | .3270 | .3807 | .2922 | .3083 |
| 2d period, . . . | .5438 | .5891 | .5114 | .5309 |
| 3d period, . . . | .4097 | .3897 | .4199 | .4195 |
| 4th period, . . . | .4986 | .4894 | .4748 | .5316 |
| Total, 4 periods, . | 1.7791 | 1.8489 | 1.6983 | 1.7903 |

| | Tank C. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . | .2970 | .3592 | .2708 | .2610 |
| 2d period, . . . | .4289 | .4607 | .4162 | .4098 |
| 3d period, . . . | .3549 | .3592 | .3238 | .3817 |
| 4th period, . . . | .4876 | .4883 | .5180 | .4566 |
| Total, 4 periods, . | 1.5684 | 1.6674 | 1.5288 | 1.5091 |

| | Tanks A. B. & C. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . | .3147 | .3686 | .2941 | .2814 |
| 2d period, . . . | .4949 | .5267 | .4825 | .4756 |
| 3d period, . . . | .4043 | .4112 | .3939 | .4078 |
| 4th period, . . . | .4944 | .4966 | .4890 | .4977 |
| Total, 4 periods, . | 1.7043 | 1.8031 | 1.6595 | 1.6625 |

*Average of Chemical Analyses.*

NATIONAL TUBE CO.

| Average of— | Car. | Phos. | Sul. | Man. | Si. | Ox. |
|---|---|---|---|---|---|---|
| Tops, . . . | .065 | .114 | .088 | .30 | .006 | .30 |
| Middles, . . | .064 | .109 | .079 | .31 | .007 | .32 |
| Bottoms, . . | .061 | .106 | .077 | .31 | .009 | .28 |
| All tubes, . . | .063 | .110 | .081 | .31 | .008 | .28 |

GOVERNMENT.

| Average of— | Car. | Phos. | Sul. | Man. | Si. | Ox. |
|---|---|---|---|---|---|---|
| Tops, . . . . | .09 | .117 | .089 | .29 | .004 | — |
| Middles, . . . | .09 | .110 | .080 | .30 | .003 | — |
| Bottoms, . . . | .09 | .105 | .080 | .33 | .002 | — |
| All tubes, . . | .09 | .111 | .083 | .31 | .003 | — |

*Recapitulation.*

SEAMLESS COLD-DRAWN.

*Average Loss (Grammes) per Square Inch.*

| | Tank G. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . . . | .3160 | .3288 | .3120 | .3074 |
| 2d period, . . . . . | .5196 | .4666 | .5278 | .5645 |
| 3d period, . . . . . | .4566 | .4796 | .4451 | .4451 |
| 4th period, . . . . . | .5071 | .5525 | .4498 | .5192 |
| Total, 4 periods, . . . | 1.7993 | 1.8275 | 1.7347 | 1.8362 |

| | Tank H. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . . . | .3511 | .2717 | .3993 | .3824 |
| 2d period, . . . . . | .5995 | .5072 | .6535 | .6380 |
| 3d period, . . . . . | .4541 | .3623 | .4901 | .5100 |
| 4th period, . . . . . | .5084 | .4891 | .5264 | .5099 |
| Total, 4 periods, . . . | 1.9131 | 1.6303 | 2.0693 | 2.0403 |

| | Tank I. | Top. | Middle. | Bottom. |
|---|---|---|---|---|
| 1st period, . . . . . | .3025 | .3205 | .2844 | .3026 |
| 2d period, . . . . . | .5501 | .5951 | .4866 | .5687 |
| 3d period, . . . . . | .4399 | .4852 | .4221 | .4125 |
| 4th period, . . . . . | .4897 | .4943 | .4500 | .5249 |
| Total, 4 periods, . . . | 1.7822 | 1.8951 | 1.6431 | 1.8087 |

| Tanks G, H and I. | Top. | Middle. | Bottom. |
|---|---|---|---|
| 1st period, . . . . . | .3232 | .3070 | .3319 | .3308 |
| 2d period, . . . . . | .5564 | .5229 | .5559 | .5904 |
| 3d period, . . . . . | .4502 | .4423 | .4524 | .4558 |
| 4th period, . . . . . | .5017 | .5119 | .4754 | .5180 |
| Total, 4 periods, . . . | 1.8315 | 1.7841 | 1.8156 | 1.8950 |

*Average of Chemical Analyses.*

NATIONAL TUBE CO.

| Average of— | Car. | Phos. | Sul. | Man. | Si. | Ox. |
|---|---|---|---|---|---|---|
| Tops, | .18 | .023 | .050 | .54 | .005 | .23 |
| Middles, | .16 | .013 | .043 | .51 | .005 | .22 |
| Bottoms, | .13 | .010 | .036 | .46 | .005 | .24 |
| All tubes, | .16 | .015 | .043 | .50 | .005 | .23 |

GOVERNMENT.

| Average of— | Car. | Phos. | Sul. | Man. | Si. | Ox. |
|---|---|---|---|---|---|---|
| Tops, | .13 | .036 | .048 | .57 | .003 | — |
| Middles, | .11 | .033 | .043 | .57 | .003 | — |
| Bottoms, | .10 | .029 | .035 | .56 | .003 | — |
| All tubes, | .11 | .033 | .042 | .57 | .003 | — |

*Recapitulation.*

LAP-WELD IRON.

*Average Loss (Grammes) Per Square Inch.*

| | Tank D. |
|---|---|
| 1st period, | .3006 |
| 2d period, | .5926 |
| 3d period, | .3737 |
| 4th period, | .5288 |
| Total, 4 periods, | 1.7957 |
| | **Tank E.** |
| 1st period, | .3342 |
| 2d period, | .5554 |
| 3d period, | .3958 |
| 4th period, | .5422 |
| Total, 4 periods, | 1.8276 |
| | **Tank F.** |
| 1st period, | .3630 |
| 2d period, | .6204 |
| 3d period, | .4203 |
| 4th period, | .3969 |
| Total, 4 periods, | 1.8006 |

| | Tanks D, E and F. |
|---|---|
| 1st period, | .3326 |
| 2d period, | .5894 |
| 3d period, | .3966 |
| 4th period, | .4893 |
| Total, 4 periods | 1.8079 |

*Average of Chemical Analyses.*

NATIONAL TUBE CO.

| Average of— | Car. | Phos. | Sul. | Man. | Si. | Ox. |
|---|---|---|---|---|---|---|
| All tubes, | Trace. | .038 | .014 | Trace. | .024 | 1.03 |

GOVERNMENT.

| Average of— | Car. | Phos. | Sul. | Man. | Si. | Ox. |
|---|---|---|---|---|---|---|
| All tubes, | .02 | .043 | .011 | .044 | .012 | — |

LAP-WELD BESSEMER STEEL TUBES.—ALKALI BATH.
FIRST PERIOD.

| Sample No. | Photo. No. | Kind of Material. | Total area in square inches. | Original weight, grammes. | Weight after sixteen weeks. | Loss in grammes. | Loss per square inch, grammes. |
|---|---|---|---|---|---|---|---|
| 3-4 | M-1 | Lap-weld Bessemer steel. | 54.192 | 495 | 492 | 3 | .0553 |
| 4-1 | M-2 | Ditto. | 54.655 | 514 | 507 | 7 | .1283 |
| 4-1-x | M-3 | Ditto. | 53.859 | 512 | 509 | 3 | .0557 |
| 4-2 | M-4 | Ditto. | 55.464 | 518 | 515 | 3 | .05409 |
| 7-3 | M-5 | Ditto. | 54.226 | 507 | 563 | 4 | .0737 |
| 12-2 | M-6 | Ditto. | 54.703 | 515 | 509 | 6 | .1096 |
| 12-3 | M-7 | Ditto. | 54.785 | 503 | 497 | 6 | .10945 |
| 12-3-x | M-8 | Ditto. | 55.907 | 537 | 519 | 18 | .2112 |

Three cubic centimeters of strong potassium hydroxide (KHO) added when test was started.

Total average of tank, .0997.

None of the tubes of any material yet show holes entirely through.

# CENTRIFUGAL PUMP TESTS.

With the introduction of the steam turbine, in which the high speed of shaft revolution precluded its successful application to the ordinary form of plunger pumps, its advocates at once turned their attention to the design of centrifugal power pumps in which the high velocities of shaft revolution of both turbines and electric motors would find a legitimate field.

With this end in view, the De Laval Steam Turbine Company worked out designs for a type of centrifugal pumps, which it had developed, and, a few years ago, commenced the manufacture of these pumps under granted patents.

The speed of the De Laval steam turbine is especially suited to the requirements of this work, and a number of these centrifugal pumps have been installed throughout the country.

On account of the valuable information obtained in connection with this subject, the following report is published of a series of exhaustive tests by Professors William Kent and J. E. Denton, at the works of the De Laval Steam Turbine Company, Trenton, N. J., upon some of the smaller sizes of their principal types of centrifugal pumps:

SYRACUSE, N. Y., *April 25, 1904.*

DE LAVAL STEAM TURBINE CO., Trenton, N. J.,

Gentlemen: We have to report as follows concerning results of the tests of the three centrifugal pumps made at your works on April 4 to April 9, inclusive.

## DESCRIPTION OF THE PUMPS.

Three pumps were tested, namely:

(No. 1.) A single-stage centrifugal pump, No. 1977, without stationary outlet guides, designed for a delivery of 1,700 gallons per minute and a lift of 100 feet when running at 1,545 revolutions per minute. This pump was driven by one of your 55-

horsepower steam turbines by direct connection with its geared shaft. Its dimensions were as follows:

| | |
|---|---|
| Diameter suction, | 8 inches. |
| discharge, | 8 inches. |
| pump wheel, | 13.75 inches. |

(No. 2.) A single-stage pump, No. 2028, without stationary outlet guides, driven by direct connection to a 20-horsepower direct-current electric motor, designed for 1,200 gallons per minute delivery, a lift of 45 feet and 2,000 revolutions per minute. The dimensions of this pump were as follows:

| | |
|---|---|
| Diameter suction, | 8 inches. |
| discharge, | 8 inches. |
| pump wheel, | 8.3 inches. |

(No. 3.) A two-stage pump, No. 2026, without stationary outlet guides, for high pressures, designed for a delivery of 250 gallons a minute, and lift of 700 feet, the large pump wheel driven at a speed of 2,050 revolutions per minute by direct connection to the geared shaft of a De Laval steam turbine, and the small wheel at 20,500 revolutions per minute by direct connection to the high-speed shaft of the motor. The dimensions of this pump are as follows:

| | Low Press. | High Press. |
|---|---|---|
| Diameter suction, | 6 inches. | 6 inches. |
| discharge, | 6 inches. | 4 inches. |
| pump wheel, | 9 inches. | 2.84 inches. |

OBJECT OF THE TESTS.

The object of the tests was to record the performance of the pumps and motors in the following particulars:

1. To measure the efficiency of the pumps, or the ratio of the water horsepower of the pumps to the brake horsepower of the motors, over a range of heads, and water delivery sufficient to determine their maximum efficiency, and at the same time show that you can control the proportions of such pumps so as to cause the maximum efficiency conditions to coincide with any

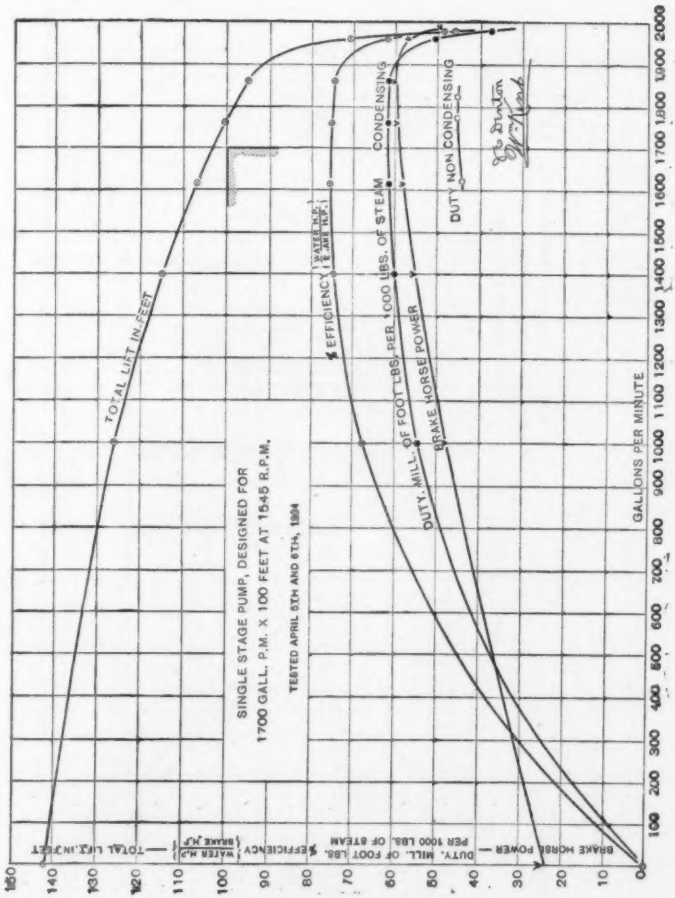

SINGLE STAGE PUMP, DESIGNED FOR
1700 GALL. P.M. X 100 FEET AT 1545 R.P.M.
TESTED APRIL 5TH AND 6TH, 1904
TOTAL LIFT IN FEET
% EFFICIENCY (WATER H.P. / BRAKE H.P.)
DUTY, MILL. OF FOOT LBS. PER 1000 LBS. OF STEAM CONDENSING
BRAKE HORSE POWER
DUTY NON CONDENSING
GALLONS PER MINUTE
BRAKE HORSE POWER — DUTY, MILL. OF FOOT LBS. PER 1000 LBS. OF STEAM — % EFFICIENCY (WATER H.P. / BRAKE H.P.) — TOTAL LIFT IN FEET

**Plate I.**

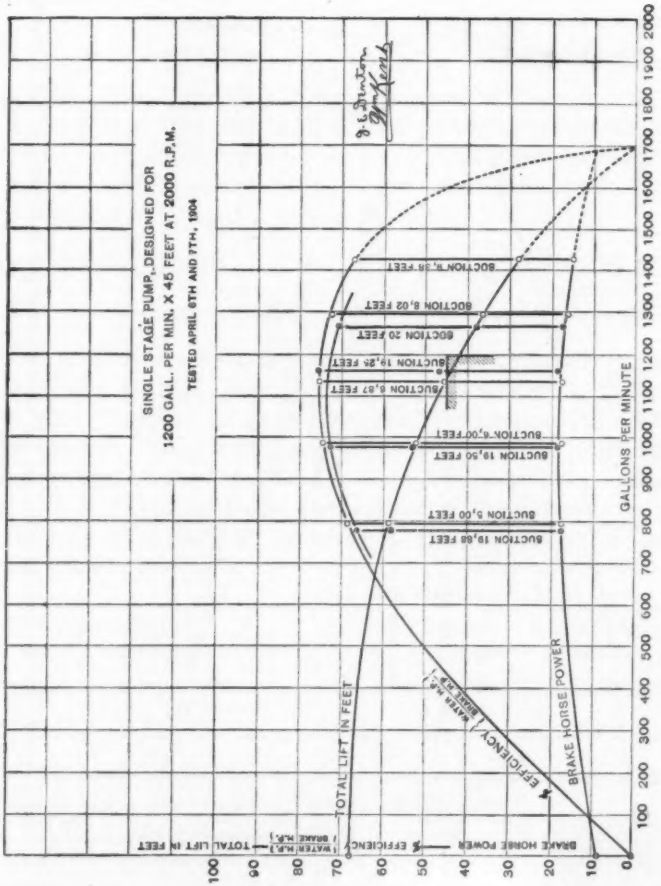

SINGLE STAGE PUMP. DESIGNED FOR
1200 GALL. PER MIN. X 45 FEET AT 2000 R.P.M.
TESTED APRIL 6TH AND 7TH, 1904
SUCTION 8,38 FEET
SUCTION 8,02 FEET
SUCTION 20 FEET
SUCTION 19,25 FEET
SUCTION 8,87 FEET
SUCTION 6,00 FEET
SUCTION 19,50 FEET
SUCTION 9,00 FEET
SUCTION 19,88 FEET
TOTAL LIFT IN FEET
EFFICIENCY
BRAKE HORSE POWER
WATER H.P. / BRAKE H.P.
GALLONS PER MINUTE
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
100 90 80 70 60 50 40 30 20 10 0

Plate II.

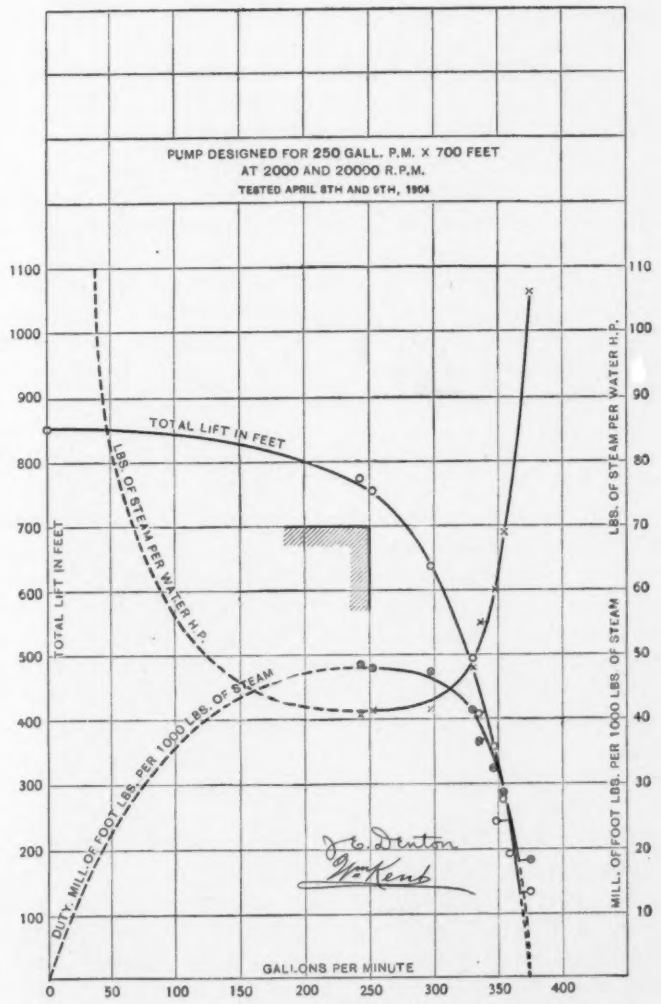

PUMP DESIGNED FOR 250 GALL. P.M. X 700 FEET
AT 2000 AND 20000 R.P.M.
TESTED APRIL 8TH AND 9TH, 1904
TOTAL LIFT IN FEET
LBS. OF STEAM PER WATER H.P.
DUTY. MILL. OF FOOT LBS. PER 1000 LBS. OF STEAM
GALLONS PER MINUTE
TOTAL LIFT IN FEET
LBS. OF STEAM PER WATER H.P.
MILL. OF FOOT LBS. PER 1000 LBS. OF STEAM
1100
1000
900
800
700
600
500
400
300
200
100
110
100
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
J. C. Denton
Wm Kent

**Plate III.**

desired amount of lift and water delivery. This object was accomplished by the direct measurement of the brake horsepower in the case of pumps No. 1 and No. 2, for which efficiency curves are given, Plates I and II. The brake horsepower of the two-stage pump, however, could not be determined without the construction of a new shaft to accommodate a prony brake. This was not feasible in the interval available for the test. The location of the conditions of maximum efficiency of the two-stage pump must therefore be inferred from the duty curve of Plate III.

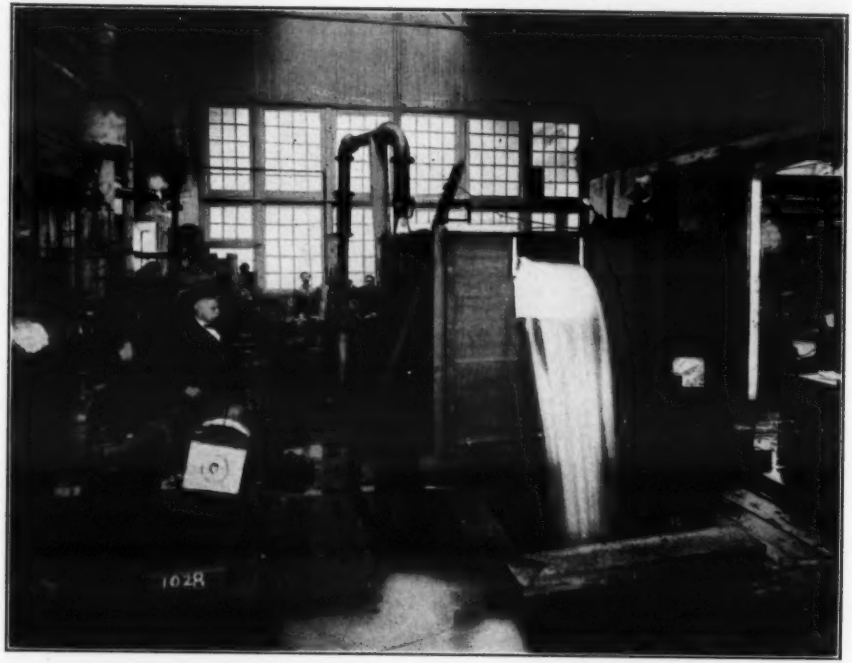
2. To determine the economy of the steam-driven pumps, as measured by the duty in millions of foot pounds per thousand pounds of commercially dry steam, or as measured by the pounds of steam consumed per hour per water horsepower. To accomplish this object, the steam consumption of the motors of pumps Nos. 1 and 3, was measured by the use of a surface condenser, and the results are shown by the duty curves of Plates I and III.

3. To provide the means of determining the economy of the electrical-driven pump by recording the brake horsepower of its motor at various lifts and water deliveries of the pump, whereby the duty of a pump, per unit of electrical energy supplied to any electric motor driving it, can be determined, when the ratio of the brake to the electric horsepower of the particular motor used is given by its makers. This object is therefore attained by the production of the "brake horsepower and gallons curve" of Plate II.

## GENERAL DESCRIPTION OF TESTS.

Each pump was arranged to lift water about 3 feet from a storage tank in the floor of the testing room, and to deliver it to a Weir tank, through a throttle valve at the outlet of the pump case, and thence through about 15 feet of pipe terminating in a vertical converging nozzle, whose outlet was located about a foot above the top of the back end of the Weir tank, as shown by the accompanying photograph. One inch below the center of the nozzle was located one end of a thin half-inch brass tube, tap-

DE LAVAL STEAM TURBINE CO.
TRENTON, N.J.
NEW YORK



ARRANGEMENT FOR THE TESTS.

ered so as to make an orifice of $\frac{3}{32}$-inch diameter (see sketch Fig. 1). The other end of this tube was connected to a vertical glass tube, fastened to the wall of the testing room, graduated in inches over a height of about 30 feet. The stream of water issuing from the nozzle impinged upon the $\frac{3}{32}$-inch orifice of the brass tube, and thereby maintained a height of water in the glass tube. This height afforded a "Pitot Tube Basis" of measurement of the quantity of water flowing, the reliability of which was tested by the flow as determined from the Weir.

Each pump was first run at its governor speed, and the delivery measured under approximately the designed total head or total lift, which was found as follows:

The total head, or total lift, is the sum of the suction and the delivery pressure, both expressed in feet head of water. The suction was determined by a mercury gauge placed in the suction pipe near the pump case, and the delivery pressure by a pressure gauge inserted in the delivery pipe near the pump, at the same level as the point of insertion of the mercury gauge. The suction pipe and delivery pipe being of same diameter, no correction for difference in velocity in these two pipes is required. In the case of the No. 3 pump the delivery pipe, where the gauge was attached, was of smaller diameter than that of the suction pipe, but the error due to neglecting this fact is insignificant in view of the high pressures involved. This total head, or total lift, was multiplied by the weight of water delivered in computing the water horsepower.

The total head was then increased and decreased during the different tests, by means of a throttle valve in the delivery pipe, and the water delivery at different heads was measured, so as to secure points of a curve of "Total lift and gallons" on either side of the designed conditions, as shown by Plates I, II and III. The total head, or total lift, with zero gallons, or with the throttle valve closed, was observed with each pump, to locate the left extremity of the curve, the tabulated data in the tables for this condition being marked "Shut-off." The conditions for which the pumps were designed is marked on the "Total lift and gallons" curve by a shaded angle.

CALIBRATION OF WEIR AND PITOT TUBE.

The dimensions of the Weir tank were 14 feet long, 6 feet wide and 6 feet deep. It was designed of such capacity that two minutes were required to fill it with the largest rate of flow through the nozzle, and the latter was so fitted that it could be swung over or off the Weir tank in less than half a second. Hence we were able to use the Weir tank as a measuring basin, to determine the rate of flow at any given reading of the Pitot tube, with an error, from spill, in diverting the stream into or out of the tank, of less than one-half of one per cent., and thereby by comparing the Pitot reading with the corresponding Weir reading, calibrate both the Weir and the Pitot tube in a very satisfactory manner. The result of such calibration with two sizes of nozzle and of Weir, show that the Francis Standard Formula $Q=3.33[L-.2h]h^{\frac{3}{2}}$ applied for the conditions of Weir used, with an error of less than one per cent., the velocity of approach being neglected, as it did not exceed one-seventh of a foot a second. The Pitot tube gave the same result as the Weir from the formula $Q'=C\times$ *Area of Nozzle* $\sqrt{2gh}$ with a value of $C$ varying only between .953 to .977 for the large nozzle and between .942 and .960 for the small nozzle. (See detailed values of $C$ on data sheets, which are given as the ratio of $Q$ to $Q'$.)

This Pitot-tube basis of measurement is that adopted in your testing room for determining the delivery of your pumps, using the value of $C$ equals 0.95, with different sizes of converging nozzles for different rates of flow, so that the value of $h$ is not less than 4 feet. It appears from the above figures that this practice is sufficiently accurate for most practical purposes, and in view of its great convenience, is to be recommended as an acceptable system for rating the capacity of your pumps.

The Weirs used were made of $\frac{1}{4}$-inch brass plate, with edges chamfered at 45 degrees, so as to leave a flat surface $\frac{1}{8}$-inch thick for the orifice. The notches were rectangular and 24 inches wide, for pumps Nos. 1 and 2, with values of $h$ varying from .8 feet to .5 feet, and 12 inches wide for No. 3 pump, the value of $h$ varying from .4 to .3 feet. The measurements of the depth of water over the Weir were made by a hook gauge

placed in a half barrel of water adjoining the tank, and connected to the latter by a 1-inch pipe, which was laid to a point in the bottom of the tank 6 feet back from the Weir, with its open end at right angles to the flow. Readings of the hook gauge were easily made to .001 feet, an incandescent lamp being used to facilitate the reading.

During preliminary tests of April 4th, the surface of the water approaching the Weir was unsatisfactorily rough, and measurements made by the Weir were inaccurate to the extent of several per cent. This roughness was overcome after some experimenting to locate boards to act as dams in the Weir tank, in addition to the grill of wooden rods and two dams of baffle boards near the entrance of the tank, which were included in the original design of the latter.

### STEAM AND ELECTRICAL MEASUREMENTS.

The steam consumption was measured by exhausting the motors into a surface condenser and weighing the delivery of the latter's air pump on a calibrated platform scale. Tests were made to determine that the delivery of the air pump was sufficiently uniform to make the steam consumption measurements over ten-minute intervals satisfactorily accurate. The quality of the steam was determined by a calorimeter, which showed moisture not exceeding 1.7 per cent. No correction was made for this moisture in computing the steam consumption, the steam being considered "commercially dry." The vacuum was measured at the exhaust chamber of the turbine by a mercury column. The steam and water gauges were calibrated by a Crosby tester. The volt and ammeters were Weston instruments, calibrated for the tests by their makers.

### PRONY BRAKE TEST.

After making the steam and water tests of the No. 1 pump on April 5th, it was removed from its base, and a Prony brake substituted to absorb the power of the turbine. This was run at the same speeds, as controlled by the governor, and the same pressures of steam below the governor valve that were used in the

## TEST OF STEAM TURBINE PUMP, No. 1,977.

Type L.P.—8. 1,700 gallons per minute—100 feet head. Pump wheel No. 509. 1,500 revolutions per minute.

| | No. of test. | Time of the test: Year, 1904. Day, Apr. 5. Hour. | Steam pressure at the governor valve, lbs. per sq. inch. Above. | Below. | Temperature of steam, degrees cent. | Nozzles opened. | Condensation, inch vacuum. | Steam used, pounds. | Revolutions per minute. | Brake H.P. calc. * | Steam per brake H.P.† | Duty millions of foot-lbs. per 1,000 lbs. of steam. | Water horsepower. | Vacuum in the suction pipe, inches mercury. | Depth of suction feet water column. | Water pressure in the discharge pipe, lbs. sq. in. | Height of water in the discharge pipe, feet. | Total head, feet. | Height of weir, feet. | Pressure in the Pitot tube, feet water. | Water, quantity, gallons per minute by weir. | Efficiency of pump. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A. M. | | | | | | | | | | | | | | | | | | | | | |
| | 1 | 11'00-11'15 | 188 | 155.2 | 190.5 | 2.4.7 9 | 25 1/8 | 358.5 | 1,553 | 59.6 | 24.06 | 61.50 | 44.54 | 14 31/32 | 16.8 | ... | 78.1 | 94.9 | .769 | 16.84 | 1,860 | .747 |
| | 2 | 11'25-11'40 | 188 | 153.5 | 191.5 | 2.4.7.9 | 25 1/4 | 356.5 | 1,547 | 58.9 | 24.21 | 61.86 | 44.55 | 13 31/32 | 15.57 | 36.75 | 84 8 | 100.37 | .740 | 15.67 | 1,759 | .756 |
| | 3 | 11'50-12'05 | 188 | 150.7 | 192.5 | 2.4.7.9 | 25 1/4 | 351 | 1,540 | 57.7 | 24.33 | 61.47 | 43.59 | 12 1/16 | 14.24 | 40.08 | 92.7 | 106.94 | .696 | 13.33 | 1,615 | .755 |
| | | P. M. | | | | | | | | | | | | | | | | | | | | | |
| | 4 | 12'15-12'30 | 188 | 143.5 | 191 | 2.4.7.9 | 25 1/4 | 336 | 1,549 | 54.8 | 24 53 | 60.00 | 40 72 | 9 1/4 | 10.76 | 45.3 | 104 7 | 115.46 | .629 | 9.75 | 1,398 | .743 |
| | 5 | 12'40-12'55 | 188 | 161 | 191.5 | 2.4.7 | 25 1/8 | 289 | 1,540 | 47.5 | 24.5 | 54.47 | 31.80 | 6 1/16 | 6.85 | 51.5 | 119 | 125.85 | .499 | 4.92 | 1,001 | .676 |
| | 6 | 1'15- 1'30 | 190 | 126 | 192 | 2.4.7.9 | 25 1/4 | 303.5 | 1,547 | 47.7 | 25 45 | 37 43 | 22.95 | 16 1/16 | 18.27 | 12 | 27.7 | 45 97 | .803 | Not taken | 1,978 | .481 |
| | 6a | 1'35- | 189.5 | 70 | 192 | 2.4.7.9 | 25 7/16 | ... | 1,565 | 24.9 | ... | Shut off test. | | | 5.95 | 59 | 136.2 | 142.15 | ... | ... | ... | ... |
| Non-condensing. | 7 | 4'00-4'10 | 189 | 169.5 | 190 | 3.6.8 | ... | 320.5 | 1,537 | ... | ... | 45 15 | 43 85 | 14 1/2 | 16.14 | 34.2 | 79.1 | 95.14 | .759 | 16.92 | 1,826 | ... |
| | 8 | 4'20- 4'30 | 189 | 169 | 191.6 | 3.6.8 | ... | 320.5 | 1,535 | ... | ... | 45.12 | 43.82 | 13 3/4 | 14.75 | 36.5 | 84.3 | 99.05 | .737 | 15 58 | 1,753 | ... |
| | 9 | 4'45- 4'55 | 189 | 169.7 | 191.6 | 3.6.8 | ... | 317.5 | 1,538 | ... | ... | 44.62 | 42.93 | 12 5/8 | 13.82 | 39.2 | 90.6 | 104.42 | .700 | 13.43 | 1,629 | ... |
| | 10 | 5'10- 5'25 | 190 | 148 | 191.5 | 2.4.7.9 | 25 1/16 | 343 | 1,536 | 56.65 | 24.42 | 50.44 | 34.95 | 15 1/16 | 17.65 | 23 | 53.1 | 70.75 | .797 | Not taken | 1,958 | .617 |
| | 10a | 5'30- | 190 | 124 | 192 | 2.7 | 26 | ... | 1,565 | 24 | ... | Shut off test. | | ... | ... | 59 | 136.2 | 142.15 | ... | ... | ... | ... |

* Formula for brake horsepower: B.H.P. = .4064 × steam pressure − 3.5.
Approximate formula for steam per B.H.P. per hour = − .117 B.H.P. + 31 03.
† Steam per B.H.P. per hour = steam per hour ÷ B.H.P. [as calculated].
Duty calculated from weir measurement
= [Q × 62.3 × 60 × total head in feet] ÷ [steam per minute × 1,000].

| Nozzles. | | | |
|---|---|---|---|
| | Nozzle No. | Size No. | Diam. M.M. |
| Condensing ..... | 2.4.7 9 | 264 | 5 7 |
| Non-condensing { | 3.8 | ... | 7.1 |
| | 6 | 104 | 7 5 |
| Blind..... | 1 5 | ... | ... |

Stroke of governor lever, .140 inch.
Suction and discharge pipe, 8 inches.

| Steam per B.H.P. per hour. | | | |
|---|---|---|---|
| B H.P. | Calc. | Formula. | Diff. |
| 47.7 | 25 45 | 25.45 | 0 |
| 54.8 | 24 53 | 24.62 | +.09 |
| 56.65 | 24.23 | 24 40 | +.18 |
| 57 7 | 24.33 | 24.28 | −.05 |
| 58.9 | 24.21 | 24.14 | −.07 |
| 59.6 | 24 06 | 24.06 | 0 |

| Cubic feet of water per sec. | | | |
|---|---|---|---|
| No. | Weir Q | Pitot Q′ | Ratio Q ÷ Q′ |
| 1 | 4.144 | 4.246 | .977 |
| 2 | 3.919 | 4.09 | .958 |
| 3 | 3.599 | 3.78 | .953 |
| 4 | 3.114 | 3.23 | .964 |
| 5 | 2 231 | 2.29 | .975 |
| 6 | 4.407 | ... | ... |
| 7 | 4.069 | 4.26 | .956 |
| 8 | 3.906 | 4.08 | .958 |
| 9 | 3.630 | 3 79 | .958 |
| 10 | 4.362 | ... | ... |
| Average | | | .963 |
| Av. omitting No. 1–5. | | | .958 |

BRAKE TEST OF STEAM TURBINE. No. 1977.

| No. of Test. | Time of the Test. Year, 1904. Day, April 6. Hour. | Steam pressure at the governor valve. Lbs. per sq. in. Above. | Below. | Temper. of steam. Deg. cent. | Steam consumption. Lbs. | Condensation. Inch vacuum. | Revolution per minute. | Nozzles opened. | Length of the brake lever. Feet. | Load on the brake lever. Lbs. | Brake horse-power. | Steam per brake H.P. per hour. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5·15–5·30 | 170 | 156 | 187 | 277 | 25⅝ | 1,540 | 2.4.7 | 3.5 | 43 | 44.2 | 34.04 |
| 2 | 5·45–6·00 | 189 | 154.3 | 193 | 358.5 | 25½ | 1,530 | 2.4.7.9 | 3.5 | 58 | 59.2 | 24.20 |
| 3 | 6·03–6·09 | 189 | 148 | 192 | ... | 25 | 1,518 | 2.4.7.9 | 3.5 | 55 | 55.6 | ... |
| 4 | 6·11–6·13 | 189 | 140 | 192 | ... | 25½ | 1,521 | 2.4.7.9 | 3.5 | 52 | 53.4 | ... |
| 5 | 6·20–6·35 | 189 | 126 | 192 | 302 | 25½ | 1,523 | 2.4.7.9 | 3.5 | 47 | 47.7 | 25.22 |
| 6 | 6·41–6·43 | 192 | 161 | 192 | ... | 25½ | 1,509 | 2.4.7 | 3.5 | 46 | 46.3 | ... |
| 7 | 6·49–6·53 | 188 | 123 | 192 | ... | 25½ | 1,518 | 2.7 | 3.5 | 23 | 23.3 | ... |

4 nozzles. Steam pressure below valve..... 154.3 lbs. 59.2 B.H.P.
4 nozzles. Steam pressure below valve..... 126 lbs. 47.7 B.H.P.

128.3 11.5

Relation of B.H.P. to steam pressure $\frac{11.5}{28.3} = .4064$

$.4064 \times 154.3 = 62.7$
$- 59.2$
$3.5$

B.H.P. $= .4064 \times$ steam pressure $- 3.5$

This formula used in calculating B.H.P. in test of pump, April 5.

| No. | St. pres. | B.H.P. Calcu. | B.H.P. Actual. | Diff. |
|---|---|---|---|---|
| 2 | 154.3 | 59.2 | 59.2 | 0 |
| 3 | 148 | 56.65 | 55.6 | 1.05 |
| 4 | 140 | 53.4 | 53.4 | 0 |
| 5 | 126 | 47.7 | 47.7 | 0 |

## TEST OF ELECTRIC MOTOR PUMP, No. 2,028.

Type G.M.P.—8. 1,200 gallons per minute.—45 feet head. Pump wheel, No. 206. 2,000 revolutions per minute.

| No. of test. | Time of the test: Year, 1904. Day, Apr. 7. Hour. | Volts. | Ampères. | E.H.P. | B.H.P.* | Revolutions per minute. | Cubic feet of water per second. Weir Q. | Cubic feet of water per second. Pitot Q'. | Ratio Q ÷ Q'. | Water horsepower. | Vacuum in the suction pipe, inches mercury. | Depth of suction, feet water column. | Water pressure in the discharge pipe, lbs. sq. in. | Height of water in the discharge pipe, feet. | Total head, feet. | Height of weir, feet. | Pressure in the Pitot tube, feet water. | Water quantity, gallons per minute by weir. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 3'40–4.04 | 242.3 | 54 8 | 17.80 | 14.94 | 1,996 | 3.126 | 3.217 | .972 | 10.67 | 9.62 | 10.9 | †16.96 | 19.22 | 30.12 | .631 | 10.29 | 1,403 |
| 3 | 4'10–4'18 | 242 | 59 | 19.14 | 16.22 | 1,996 | 2.885 | 2.977 | .970 | 11.80 | 8.02 | 9.1 | 11.7 | 27 | 36.1 | .597 | 8.29 | 1,295 |
| 4 | 4'25–4'39 | 241.8 | 62 9 | 20.39 | 17.41 | 2,000 | 2.525 | 2.603 | .971 | 13 06 | 6.87 | 7.78 | 16.4 | 37.88 | 45.66 | .5435 | 6.33 | 1,133 |
| 5 | 4'45–4'53 | 241 4 | 64 | 20.71 | 17.71 | 2,003 | 2.197 | 2.251 | .976 | 13.12 | 6 | 6.8 | 19.8 | 45.9 | 52.7 | .494 | 4.75 | 986 |
| 6 | 5'05–5'15 | 242 | 62 | 20.11 | 17.14 | 2,003 | 1.760 | 1.803 | .976 | 11.71 | 5 | 5.66 | 23 | 53.1 | 58.76 | .424 | 3.04 | 790 |
| 7 | 5'20–5'26 | 242.5 | 55.2 | 17.94 | 15.07 | 2,006 | 3.158 | 3 290 | .961 | 10.25 | 9.38 | 10.6 | ... | 17.92 | 28.52 | .6375 | 10.125 | 1,417 |
| 8 | 5'35–5'43 | 242 | 62.4 | 20.24 | 17 27 | 2,005 | 2.826 | 2 910 | .972 | 12 18 | 20 | 22.65 | †13.59 | 13.4 | 38.05 | .588 | 7 92 | 1,268 |
| 9 | 5'52–6'00 | 240.8 | 66 | 21.30 | 18.28 | 2,005 | 2.504 | 2.602 | .964 | 13.40 | 19.25 | 21.8 | †22.45 | 25.45 | 47.25 | .546 | 6.33 | 1,124 |
| 10 | 6'05–6'12 | 239.7 | 66.3 | 21.30 | 18.28 | 1,997 | 2.179 | 2.244 | .972 | 13.15 | 19.5 | 22.1 | 12.5 | 31.18 | 53.28 | .491 | 4.71 | 978 |
| 11 | 6'20–6'28 | 240.9 | 63.2 | 20.41 | 17.43 | 2,007 | 1.735 | 1.791 | 969 | 11.42 | 19.88 | 22 3 | 15.5 | 35.8 | 58.10 | .420 | 3.00 | 779 |
| 12 | 6'35 Shut off. | 248 | 34 | 11.30 | 8.74 | 2,040 | ... | ... | ... | ... | ... | ... | ... | ... | 68.39 | ... | ... | ... |

*B.H P. calculated from formula B.H.P. = .954 E.H.P. — 2.04. † Mercury gauge in discharge pipe. Pump wheel, outside diameter, $8\frac{5}{32}$ inches.

Tests 1 to 7, suction valve wide open; tests 7 to 11, suction valve throttled; test 7, delivery valve wide open.

BRAKE TEST ON MOTOR No. 2028.

| No. of test. | Time of the test. Year, 1904. Day, April 6. Hour. | Volts. | Amp. | E.H.P. | Revolutions per minute. | Length of the brake lever. Feet. | Load on the brake lever. Lbs. | Brake H.P. | Brake H.P. calculated by formula. | Difference. | Efficiency per cent. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2·38–3·08 | 240 | 76.5 | 24.61 | 2,004 | 1.75 | 32 | 21.38 | 21.43 | + .05 | .868 |
| 2 | 3·10–3·20 | 241 | 61.2 | 19.77 | 2,034 | 1.75 | 25 | 16.98 | 16.82 | — .16 | .859 |
| 3 | 3·22–3·30 | 243 | 50.3 | 16.38 | 2,040 | 1.75 | 20 | 13.60 | 13.58 | — .02 | .830 |
| 4 | 3·32–3·40 | 243.5 | 39 | 12.73 | 2,051 | 1.75 | 15 | 10.25 | 10.10 | — .15 | .805 |
| 5 | 3·42–3·52 | 244 | 28.5 | 9.32 | 2,060 | 1.75 | 10 | 6.87 | 6.85 | — .02 | .737 |
| 6 | 3·54–4·02 | 244 | 17.6 | 5.76 | 2,070 | 1.75 | 5 | 3.45 | 3.46 | + .01 | .599 |
| 7 | 4·04–4·12 | 239.5 | 77.6 | 24.92 | 2,037 | 1.75 | 32 | 21.75 | 21.75 | ... | .872 |
| 8 | 4·16– | 244 | 17.5 | 5.74 | 2,080 | 1.75 | 5 | 3.47 | 3.42 | — .05 | .606 |
| 9 | 4·22–4·26 | 245 | 6.5 | 2.135 | 2,088 | 1.75 | Brake off. | ... | ... | ... | ... |

Formula for relation of B.H.P to E.H.P. : B.H.P. = .954 E.H.P. — 2.04.

## TEST OF STEAM TURBINE HIGH-PRESSURE PUMP, No. 2026.

Type L.X.P.—3. Compound. 250 gall. per minute.—700 feet. Rev. per min.: Pump Wheel No. 12—2,050 R.P.M.; Pump Wheel No. 02—20,500 R.P.M.

| No. of test. | Time of the test. Year, 1904. Day, Apr. 8. Hour. | Steam pressure at the governor valve. Lbs. per square inch. Above. | Below. | Temperature of the steam. Deg. cent. | Pressure between pumps. Lbs. per square inch. | Condensation. Inches vacuum | Steam consumption. Lbs. | Revolutions per minute. | Cubic feet of water per second. Weir Q. | Pitot Q'. | Ratio Q ÷ Q'. | Water horsepower. | Vacuum in the suction pipe. Inches mercury. | Depth of suction, feet. Water column. | Water pressure in discharge pipe. Lbs. per sq. in. | Height of water in the discharge pipe. Feet. | Total head. Feet. | Height of Weir. Feet. | Pressure in the Pitot tube. Feet, water. | Water, quantity, gallons per minute by weir. | Duty. Millions of foot-lbs. per 1,000 lbs. of steam. | Lbs. of steam per W.H.P. per hour. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5'05-5'20 | 186 | 120.7 | 189 | 28.1 | 25¼ | 341 | 2,104 | .830 | .876 | .947 | 12.83 | 8.62 | 9.76 | 55 | 126 | 135.76 | .420 | 11.42 | 373 | 18.63 | 106.2 |
| 2 | 5'20-5'35 | 175 | 138 3 | 189 | 27.5 | 24.4 | ... | 2,092 | 799 | .844 | .947 | 17.54 | 8.25 | 9.35 | 80 | 184.5 | 193 85 | .409 | 10.62 | 359 | ... | ... |
| 3 | 5'40-5'55 | 181 | 162.3 | 190.5 | 27.05 | 25 5 | 385 | 2 074 | .790 | .833 | .948 | 25 78 | 7.94 | 9.00 | 121 | 279 | 288 | .405 | 10.33 | 354 | 28.73 | 68.3 |
| 4 | 6'00-6'10 | 178 | 173 7 | 189 | 26 2 | 25.5 | 316 | 2,056 | .775 | .817 | .950 | 31 50 | 7.75 | 8.78 | 151.6 | 350 | 358.78 | .400 | 9.92 | 347 | 32.9 | 60.2 |
| 5 | 6'15-6'25 | 180 | 180.3 | 190 | 26 | 25 3 | 326 | 2,027 | .750 | .792 | .949 | 35.60 | 7.5 | 8 50 | 178 7 | 412 | 420.5 | .391 | 9.93 | 336 | 36.004 | 54.9 |
| 6 | 6'30-6'40 | 181 | 182 | 190 | 25 3 | 25.25 | 325 | 2,001 | .731 | .774 | .945 | 40.92 | 7.375 | 8.35 | 210.3 | 486 | 494.35 | .384 | 8.92 | 328 | 41.55 | 47.7 |
| 7 | 6'45-6'55 | 180 | 182 | 190 | 24 9 | 25 35 | ... | 1,962 | .697 | .735 | .949 | 46.19 | 7.125 | 8.06 | 250 | 577 | 585.06 | .371 | 8.04 | 312 | ... | ... |
| 8 | 7'05-7'15 | 185 | 185 | 191 | 30.0 | 25.3 | 331 | 2,012 | .558 | .594 | .942 | 47.81 | 5.625 | 6.38 | 325 | 750 | 756.38 | .318 | 5.25 | 251 | 47 67 | 41.5 |
| | April 9. | | | | | | | | | | | | | | | | | | | | | |
| 1 | 12'05-12'15 | 186 | 188.3 | 190 | 25.5 | 26.3 | 331 | 2,014 | .664 | .695 | .955 | 47.58 | 8.46 | 9.58 | 270 | 623 | 632.6 | .359 | 7.21 | 299 | 47.43 | 41.77 |
| 2 | 12'20-12'30 | 185 | 184 | 190 | 29 | 26 5 | 325 | 2,029 | .544 | .567 | .959 | 48.15 | 6 54 | 7.41 | 335 | 774 | 781.4 | .312 | 4.79 | 244 | 48.88 | 40.50 |
| | 12'55 shut off | 185 | 109 | ... | ... | 26.5 | .. | ... | ... | ... | ... | ... | ... | 6.37 | ... | ... | 855 | ... | ... | ... | ... | ... |

Steam nozzles in turbine.

| No. | Size No. | Diam. M.M. |
|---|---|---|
| 1, 2, 3, 4, 5, 6, 7, 9 | 274 | 4.4 |

Water nozzle diameter, 2.433".
Water nozzle area, .0323 square feet.
Length of weir, 12 inches.

Barometer pressure, 29.854 inches.
Temperature of the room, 67.4° Fahr.
Moisture in steam:
Four tests gave—1.7 per cent ; 1.1 per cent. ; .75 per cent. ; .9 per cent.

Temperature of condensed water leaving, 24°C.
Temperature of condensed water entering, 17.5°C.
Temperature of water in tank, 22° C = 72° F.
Weight of Water per cubic foot, 62.3 lbs.
Suction valve wide open.

previous tests of the pump. The steam used by the turbine was again measured and found practically to agree with the steam used by it when driving the pump at the same speed, and with the same steam pressures, and by plotting the record of brake horsepower and steam pressure it was found that the results formed a straight line, giving the following formula:

$$\text{B.H P.} = .4064 \times \text{steam press.} - 3.5.$$

This formula was used in calculating the brake horsepower of the test of the large turbine on April 5th.

In like manner the pump driven by the electric motor was removed from its base, a Prony brake substituted, and the motor then run at the same volts and ampères as were used during the test of the electric-motor pump. These brake tests also gave a straight line formula connecting the brake horepower and electric horsepower, which is

$$\text{B.H.P.} = .954\ \text{E.H.P.} - .204.$$

The tables herewith enclosed and the curves made from them show the complete record of results. They may be briefly summarized as follows:

CONCLUSIONS.

The large steam-driven pump designed for 1,700 gallons and 100 feet of total lift delivered a maximum quantity of 1,978 gallons per minute against a total lift, including suction, of 46 feet, the delivery decreasing to 1,759 gallons per minute for a total lift of 100 feet and to 1,001 gallons per minute for a lift of 126 feet. When the delivery valve was shut, the maximum pressure shown was equivalent to a lift of 142 feet with no delivery.

The water horsepower of the pump was at a maximum of 44½ horsepower for a delivery of 1,760 and 1,860 gallons and corresponding to lifts of 100 and 95 feet, and the horsepower decreased when the delivery was either increased above 1,860, with diminishing head, or was decreased below 1,760 gallons with increasing head. The efficiency of the pump, which is the ratio of the water horsepower to the calculated brake horsepower, ranged from .743 to .756 for delivery between 1,398 and 1,860 gallons

per minute, decreasing as the delivery was either decreased or increased beyond these limits. The duty of the pump when the turbine was running condensing ranged from 60 to 61.86 millions of foot pounds per 1,000 pounds of steam within the same limits, decreasing to 54.47 million foot pounds for a delivery of 1,001 gallons against a total lift of 126 feet, and to 37.43 millions at the maximum delivery of 1,978 gallons per minute against a total lift of 46 feet. Three tests were made with the turbine running non-condensing, which gave a duty ranging from 44.6 to 45.15 millions, for deliveries of 1,629 to 1,826 gallons, and total heads, respectively, of 104.42 and 95.14 feet.

The steam per brake horsepower, running condensing, ranged between 24.06 and 24.53 for delivery between 1,398 and 1,860 gallons per minute, corresponding to heads of 115.5 and 95 feet. These deliveries and heads therefore cover the economical range of the pump, and show that the conditions for which it was designed coincide with those of maximum efficiency.

The tests of the electrical motor pump, designed for 1,200 gallons at 45 feet lift, showed a delivery ranging from 790 to 1,403 gallons per minute at total lift heads, respectively, of 59 and 30 feet. The electrical horsepower was 20.11, or 17.14 brake horsepower for the smallest delivery at the highest head, and 17.80 electrical horsepower, or 14.94 brake horsepower for the largest delivery at the smallest head.

The maximum electric horsepower, or 17.72 brake horsepower, was attained at a delivery of 986 gallons per minute, and a total head of 53 feet. The efficiency of the pump, which is measured by the quotient of the water horsepower divided by brake horsepower, ranged from .714 for the maximum delivery of 1,403 gallons a minute to .750 for a delivery of 1,133 gallons, falling to .683 for the minimum delivery of 790 gallons a minute at the highest head of 59 feet. Four tests of this pump were made with the suction throttled to a constant suction lift of 20 feet, to determine if the throttling made any change in the efficiency. With throttled suction, the range of efficiency was .655 to .733, showing a decreased efficiency of only about 2 per cent.

The two-stage, or compound pump, designed for 250 gallons

at 700 feet head, showed a delivery of from 244 to 373 gallons per minute against heads, respectively, of 781 and 136 feet. The water horsepower increased from 12.83, corresponding to 373 gallons delivered at 136 feet head, to 48.15 for 244 gallons delivered at 781 feet head. The duty in million foot pounds was a maximum of 48.88 for delivery at the highest head and decreased to 41.55 for 328 gallons delivery at 494 feet head, and to 18.63 millions for the maximum delivery of 373 gallons at the head of 136 feet. The steam per water horsepower per hour ranged from 40.5 for the maximum horsepower and highest head to 106.2 for the maximum delivery, lowest head and lowest horsepower. This lowest horsepower is only about one-fourth of the highest horsepower delivered by the pump. Both the electrical and two-stage pumps therefore realize their maximum efficiencies at practically the designed conditions of lift and water delivery.

Very Respectfully,

WM. KENT,
J. E. DENTON.

# EXPERIMENTS ON THE OUTFLOW OF STEAM.

By Prof. M. F. Gutermuth, Mechanical Laboratory of the Technical High School, Darmstadt.

[Translated from the "Zeitschrift des Vereines Deutscher Ingenieure," Jan. 16, 1904, by William Wachsman, Associate Member.]

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The uncertainty still existing in the calculative pursuit of the flow of steam through the ports of steam engines and the meager fundamental principles for calculating the sizes of the valve details connected therewith, have prompted me to carry out experiments at the mechanical laboratory of the Technical High School at Darmstadt on the outflow of steam through openings of various cross-sectional shapes. In addition, a connected series of tests for different conditions of outflow was made to aid in verifying the range of validity of the theoretical formulæ for outflow, as well as to throw further light on the conditions of the flow of steam through nozzles of steam turbines. As a matter of fact, valuable results have been obtained in these different directions.

Moreover, in connection with this, a critical investigation of the valve gears of the steam engines of the laboratory were undertaken.

To provide the test equipment and to cover the costs I have had the willing support of the Society of German Engineers.

## EXPERIMENTAL APPARATUS, FIGS. 1 TO 4.

To obtain reliable results especial stress at the outset had to be laid on the use of dry steam. To obtain this, the steam, after leaving the boiler and before entering the outflow vessel, was dried in a nest of pipes or super-heated by several degrees.

A sectional view of this drier is shown in Fig. 3.

The steam enters the cylindrical space *A*, and from here it is conducted in the manner indicated by the arrows, through a

large number of small copper tubes, which terminate in chest *B*. The tube surface amounts to 8 square meters.

The tubes are all grouped concentrically, so that their areas, by means of adjustable concentric rings *r*, operated by a spindle, can be entirely shut off or can be more or less reduced. By this means the throttling of the steam can be easily regulated for the pressures existing in the cylindrical space, and at the same time

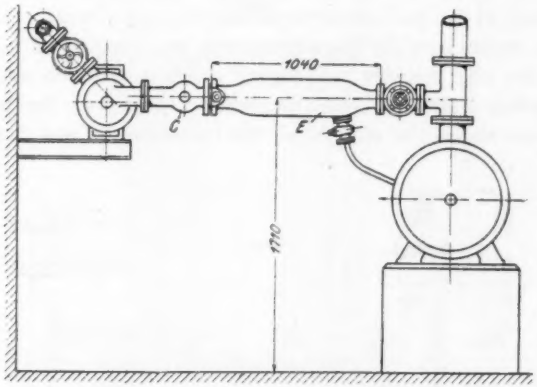


**Fig. 1.**—EXPERIMENTAL APPARATUS.

the latter acts as a jacket for the steam. By combining the two operations the steam is not only completely dried, but is also super-heated, depending on its initial state and the manner of throttling.

Connected to this steam drier is a pipe and spherical piece *C*, Fig. 4, which forms the real outflow vessel, the branch *D* being closed by a flat plate *P* containing the outflow orifice. Hereupon follows the steam receiving cylinder *E*, from which the steam passes to the surface condenser of the 100-horsepower steam engine of the laboratory.

To enable the issuing steam jet to be observed, sight glasses *G* are provided in the plane of the outflow orifice, by means of which the steam jet can be externally illuminated by an electric incandescent light.

For following up the condition of the steam in front and back of the outflow orifice the pressures and temperatures of the steam were measured by test gauges $M_1$ to $M_4$ and with carefully-graduated mercury thermometers $T_1$ to $T_4$.

Between outflow vessel and steam supply pipe, as well as between receiving vessel and condenser, regulating valves $R_1$ and $R_2$ were inserted, by which, in combination with the throttling rings $r$, Fig. 3, a constant pressure could be maintained in front and back of the outflow orifice during an experiment.

The steam used for the experiments was condensed by water from the city main in the engine condenser, which was tested for perfect tightness before beginning the tests; for terminal pressures above the outside air the condensation was drawn off

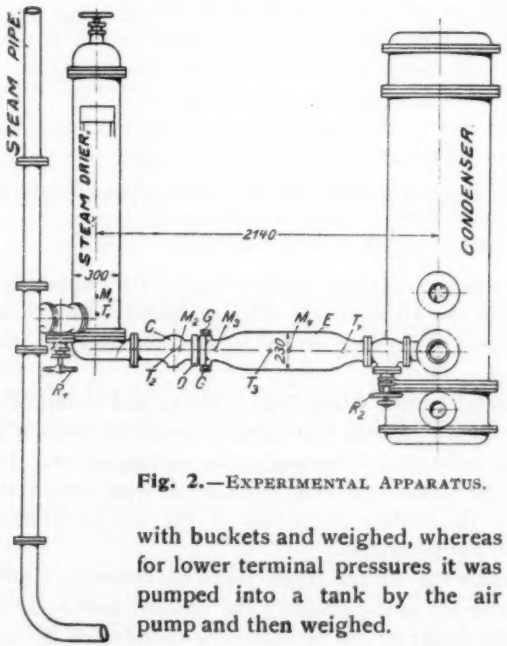


Fig. 2.—EXPERIMENTAL APPARATUS.

with buckets and weighed, whereas for lower terminal pressures it was pumped into a tank by the air pump and then weighed.

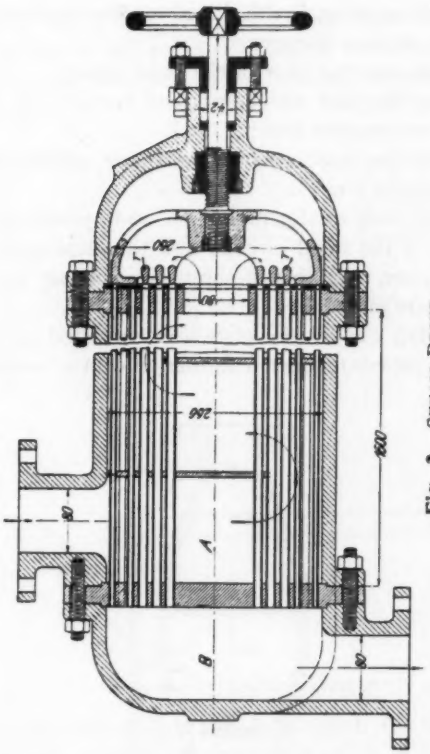

Fig. 3.—Steam Drier.

EXPERIMENTS.

The extent of the experiments covers the comparative establishment of the steam volumes flowing out for various-shaped orifices of the same area, as well as for different areas and similar shape, and for varied steam pressures on either side of the orifice.

The following orifices have been investigated, Fig. 5.

I: circular hole of 5.4 mm. diam. and cylindrical shape;

II: circular hole of 5.4 mm. diam. with funnel-shaped transition;

III: rectangular port of equal area to the circular opening;

IV: circular opening I with Laval nozzle attachment having 2.5 degrees divergence;

V: circular opening II with the same nozzle;

VI: rectangular port with compound curved-pipe attachment of rectangular area;

VII: rectangular port with straight-pipe attachment of rectangular area;

VIII: circular hole of 16.2 mm. diam. and cylindrical in shape.

The areas of the small circular and the rectangular openings were 22.9 square mm., that of the larger opening was 9 by 22.9 = 206.1 square mm.

The carrying out of the tests was entrusted to Mr. Blaess, Government superintendent, a former student of mechanical en-

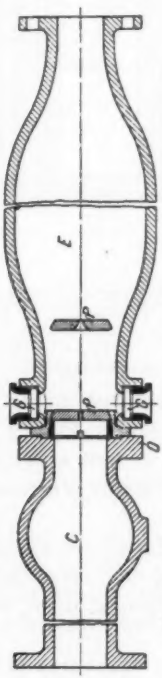


Fig. 4.—Outflow Vessel with Sight-glass Arrangement.

gineering at the Technical High School at Darmstadt, whose conscientiousness and solicitude during the observations, and whose intelligent treatment of the results, I herewith especially acknowledge.

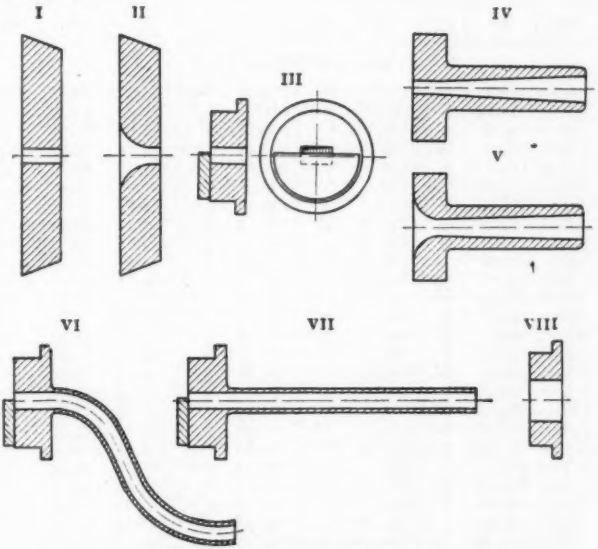


**Fig. 5.**—OUTFLOW ORIFICES.

Nearly 300 tests were made, from which the following were selected as especially prominent and of which an abstract is made for conditions mainly dissimilar from each other. Connected series of tests were thereby obtained by maintaining a constant pressure in the outflow vessel, and varying the pressure in the receiving vessel for progressive pressure differences, from the smallest to the highest, corresponding to the boiler pressure available and to the vacuum attainable in the condenser.

For each test the pressures and temperatures were noted every ten minutes and the amount of condensation weighed. In the following tables are compiled the hourly average values of each test of the eight series for the different shaped opening I to VIII:

| No. of test. | Steam pressures ($p$) in atmos. abs., and steam temperatures ($t$) in °C. | | | | | | | | Outflow volume per | | Sight glass. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | In front of the outflow opening. | | | | Back of the outflow opening. | | | | Hour. | Min. | |
| | $p_1$ | $t_1$ | $p_2$ | $t_2$ | $p_3$ | $t_3$ | $p_4$ | $t_4$ | kg. | kg. | |
| | | | | | ORIFICE SHAPE No. I. | | | | | | |
| 1 | 9.05 | 173.5 | 9 | 174 | 8.8 | 173.08 | 8.8 | 173 | 28.10 | 0.468 | * |
| 2 | 9.05 | 173.25 | 9 | 174 | 8.5 | 171.75 | 8.5 | 171.75 | 43.20 | 0.720 | * |
| 3 | 9.15 | 173.5 | 9 | 174 | 8 | 169.71 | 8 | 169.07 | 60.86 | 1.013 | * |
| 4 | 9.04 | 173.5 | 9.03 | 174.16 | 7.03 | 164.41 | 7.03 | 164 | 79.8 | 1.33 | * |
| 5 | 9.05 | 173 | 9 | 174 | 6.5 | 161.08 | 6.5 | 161.08 | 85.85 | 1.431 | * |
| 6 | 9.04 | 173.25 | 9 | 174 | 6 | 160 | 6 | 159.91 | 90.05 | 1.501 | * |
| 7 | 9.1 | 173.25 | 9 | 174 | 5 | 156.17 | 5 | 155.67 | 93.2 | 1.553 | † |
| 8 | 9.15 | 173.4 | 9 | 173.93 | 4 | 155.14 | 4 | 154.7 | 94.93 | 1.582 | † |
| 9 | 9.05 | 173.5 | 9 | 174 | 3 | 150 | 3 | 149.17 | 95.25 | 1.587 | † |
| 10 | 9.1 | 173.5 | 9.01 | 174.08 | 2.01 | 147.33 | 2 | 146.5 | 95.35 | 1.589 | † |
| 11 | 9.17 | 173 | 9.01 | 174.2 | 1. | 144 | 1 | 143.84 | 95.61 | 1.593 | † |
| 12 | 8.05 | 168.5 | 8 | 169 | 7.8 | 168.25 | 7.8 | 168.25 | 26.6 | .443 | * |
| 13 | 8.05 | 168.5 | 8 | 169 | 7.5 | 165.83 | 7.5 | 166.83 | 39.85 | .664 | * |
| 14 | 8.03 | 168.5 | 8 | 169.25 | 7 | 164.16 | 7 | 164.16 | 56.91 | .948 | ‡ |
| 15 | 8.05 | 168 | 8 | 169 | 6 | 158.33 | 6 | 158.33 | 73.6 | 1.227 | * |
| 16 | 8.05 | 168.5 | 8 | 169.16 | 5 | 154.58 | 5 | 154.58 | 81.9 | 1.365 | * |
| 17 | 8.05 | 169 | 8 | 169.41 | 4 | 151.33 | 4 | 151.33 | 85.05 | 1.417 | † |
| 18 | 8.05 | 169 | 8 | 169 | 2 | 148.83 | 2 | 148.83 | 84.75 | 1.412 | † |
| 19 | 8.01 | 168.25 | 8 | 169 | 1 | 141.41 | 1 | 141.41 | 84.35 | 1.406 | † |
| 20 | 7.05 | 163.75 | 7 | 163.83 | 6.8 | 162.83 | 6.8 | 162.83 | 23.05 | .384 | * |
| 21 | 7.05 | 163 | 7 | 164 | 6.5 | 161.17 | 6.5 | 161.16 | 37.95 | .632 | * |
| 22 | 7.05 | 163.75 | 7 | 164.33 | 6 | 158.83 | 6 | 158.83 | 53.9 | .898 | * |
| 23 | 7.05 | 163.6 | 7 | 164 | 5 | 151.67 | 5 | 151.67 | 68.25 | 1.137 | * |
| 24 | 7.05 | 163.5 | 7 | 163.75 | 4 | 147.58 | 4 | 147.58 | 73 | 1.217 | * |
| 25 | 7.05 | 163.25 | 7 | 163.92 | 3 | 145.17 | 3 | 145.17 | 74.85 | 1.247 | † |
| 26 | 7.05 | 163.25 | 7 | 163.9 | 1 | 137.92 | 1 | 137.92 | 74.85 | 1.247 | † |
| 27 | 6.05 | 157.5 | 6 | 157.91 | 5.5 | 155 | 5.5 | 155 | 34.85 | .581 | † |
| 28 | 6.05 | 157.5 | 6 | 158.08 | 5 | 152.08 | 5. | 152.08 | 48.7 | .812 | * |
| 29 | 6.05 | 157.5 | 6 | 157.75 | 4 | 145.17 | 4 | 145.17 | 60.95 | 1.016 | * |
| 30 | 6.05 | 157.75 | 6 | 158 | 3 | 141.33 | 3 | 141.33 | 63.9 | 1.065 | † |
| 31 | 6.05 | 158 | 6 | 158.33 | 1 | 132.25 | 1 | 132.25 | 64.9 | 1.082 | † |
| 32 | 5.05 | 151 | 5 | 150.92 | 4.5 | 148 | 4.5 | 148 | 31.95 | .532 | ‡ |
| 33 | 5.05 | 150.75 | 5 | 151 | 4 | 144.75 | 4 | 144.75 | 42.5 | .708 | * |
| 34 | 5.05 | 150.75 | 5 | 151 | 3 | 136.5 | 3 | 136.5 | 52.25 | .871 | ‡ |
| 35 | 5.05 | 151 | 5 | 151.17 | 1 | 128.25 | 1 | 128.25 | 54.2 | .903 | † |
| 36 | 4.05 | 143.5 | 4 | 143.58 | 3.5 | 143.42 | 3.5 | 143.42 | 28.95 | .482 | ‡ |
| 37 | 4.05 | 143 | 4 | 143.25 | 3 | 134.75 | 3 | 134.75 | 38.15 | .636 | * |
| 38 | 4.05 | 143.25 | 4 | 143.25 | 1 | 122.83 | 1 | 122.83 | 43.55 | .726 | † |
| 39 | 3.05 | 133.5 | 3 | 133.5 | 2.5 | 128.17 | 2.5 | 128.17 | 24.65 | .411 | ‡ |
| 40 | 3.05 | 132.5 | 3 | 133.17 | 1 | 114.58 | 1 | 114.58 | 32.75 | .546 | † |
| 41 | 2.05 | 121 | 2 | 120.75 | 1.5 | 115.33 | 1.5 | 115.33 | 17.45 | .291 | * |
| 42 | 2.05 | 121 | 2 | 120.83 | 1 | 105 | 1 | 105 | 22.7 | .378 | † |

Indices 1 to 4 for $p$ and $t$ refer to the points of measurement, see Fig. 2.

The steam in regard to dryness after having passed through the orifice varied for the different test numbers. The condition of the steam was indicated on the sight glass in such a way that it was either perfectly pure and dry or showed a precipitation of steam vapor. The sight glass remained dry as soon as the outflowing steam was perceptibly super-heated, as is shown by the temperatures $t_5$ and $t_6$.

* Wet. † Dry. ‡ Nearly dry.

| No. of test. | Steam pressures ($p$) in atmos. abs., and steam temperatures ($t$) in °C'. In front of the outflow opening. | | | | Back of the outflow opening. | | | | Outflow volume per Hour. | Outflow volume per Min. | Sight glass. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $p_1$ | $t_1$ | $p_2$ | $t_2$ | $p_3$ | $t_3$ | $p_4$ | $t_4$ | kg. | kg. | |
| | | | | | ORIFICE SHAPE No. II. | | | | | | |
| 43 | 9.1 | 173.75 | 9 | 174.23 | 8.8 | 172.96 | 8.8 | 172.96 | 39.86 | .664 | * |
| 44 | 9.1 | 174 | 9 | 174.13 | 8.5 | 171.75 | 8.5 | 171.75 | 55.9 | .932 | * |
| 45 | 9.18 | 173.75 | 9 | 174.63 | 8 | 174 | 8 | 174 | 75.2 | 1.253 | * |
| 46 | 9.1 | 173.75 | 9 | 174.2 | 7 | 163.92 | 7 | 163.92 | 94.2 | 1.57 | * |
| 47 | 9.1 | 174 | 9 | 174.22 | 6 | 160 | 6 | 160 | 106.1 | 1.768 | * |
| 48 | 9.1 | 173.5 | 9 | 174.52 | 5 | 158 | 5 | 158 | 109.1 | 1.818 | † |
| 49 | 9.1 | 173.75 | 9 | 174.03 | 5 | 156 | 5 | 156 | 108.5 | 1.808 | † |
| 50 | 9.1 | 173.25 | 9 | 174.37 | 4 | 152.42 | 4 | 152.42 | 108.8 | 1.813 | † |
| 51 | 9.2 | 173.5 | 9 | 174.63 | 3 | 151.33 | 3 | 151.33 | 108.5 | 1.808 | † |
| 52 | 9.1 | 173.5 | 9 | 174.27 | 2 | 147.5 | 2 | 147.5 | 109.05 | 1.817 | † |
| 53 | 9.1 | 174 | 9 | 174.27 | 1 | 143.92 | 1 | 143.92 | 108 6 | 1.81 | † |
| 54 | 9.2 | 173.75 | 9 | 174.04 | 1 | 141.5 | 1 | 141.5 | 108.34 | 1.806 | † |
| 55 | 9 | 173 | 9 | 174.45 | 1 | 140 83 | 1 | 138 | 108.3 | 1.805 | † |
| 56 | 9.1 | 173.5 | 9 | 174.55 | 1 | 140.67 | 1 | 140.67 | 108.9 | 1.815 | † |
| 57 | 9 | 172.75 | 9 | 174.17 | $\frac{9}{16}$ | 136 | $\frac{9}{16}$ | 126 | 106.4 | 1.773 | † |
| 58 | 8 | 167.75 | 8 | 169.58 | 7.8 | 168.75 | 7.8 | 168.75 | 28.2 | .47 | * |
| 59 | 8 | 168.5 | 8 | 169.7 | 7.8 | 168.1 | 7.8 | 168 | 33.7 | .562 | * |
| 60 | 8.1 | 168.5 | 8 | 169.6 | 7.8 | 168.08 | 7.8 | 168.08 | 36.45 | .607 | * |
| 61 | 8.1 | 169 | 8 | 169.65 | 7.5 | 166.92 | 7.5 | 166.92 | 52.05 | .867 | * |
| 62 | 8.1 | 168.75 | 8 | 169.47 | 7.2 | 165.17 | 7.2 | 165.17 | 63.45 | 1.058 | * |
| 63 | 8.1 | 169 | 8 | 169.82 | 7 | 165.17 | 7 | 165.17 | 70.65 | 1.177 | * |
| 64 | 8.1 | 168.5 | 8 | 169.47 | 6 | 158.25 | 6 | 158.25 | 87.05 | 1.451 | * |
| 65 | 8.1 | 169.15 | 8 | 178.6 | 5 | 154.75 | 5 | 154.75 | 95.9 | 1.598 | * |
| 66 | 8.1 | 169 | 8 | 169.82 | 4 | 149 | 4 | 149 | 99.3 | 1.655 | † |
| 67 | 8.1 | 168.75 | 8 | 169.57 | 3 | 146.67 | 3 | 146.67 | 97.1 | 1.618 | † |
| 68 | 8.1 | 168.75 | 8 | 169.22 | 2 | 144.5 | 2 | 144.5 | 98.7 | 1.645 | † |
| 69 | 8.1 | 169 | 8 | 169.32 | 1 | 141.75 | 1 | 141.75 | 97.25 | 1.62: | † |
| 70 | 7 | 162.5 | 7 | 164.56 | 6.8 | 163.5 | 6.8 | 163 | 24.7 | .412 | † |
| 71 | 7 | 162.75 | 7 | 163.92 | 6 | 158.6 | 6 | 158.5 | 61.2 | 1.02 | ‡ |
| 72 | 7 | 163 | 7 | 164.17 | 5 | 153 | 5 | 153 | 78.6 | 1.31 | ‡ |
| 73 | 7 | 163.75 | 7 | 164.08 | 4 | 148 | 4 | 148 | 85.9 | 1.432 | * |
| 74 | 7.1 | 163.25 | 7 | 164.17 | 3 | 145.67 | 3 | 145.67 | 86.3 | 1.438 | † |
| 75 | 7.1 | 163.5 | 7 | 164.5 | 2 | 143 | 2 | 143 | 86.9 | 1.448 | † |
| 76 | 7 | 163.1 | 7 | 164.07 | 2 | 141.33 | 2 | 138 | 84.55 | 1.409 | † |
| 77 | 7.05 | 163.75 | 7 | 164 | 1 | 135.08 | 1 | 135.08 | 84.8 | 1.413 | † |
| 78 | 7 | 162 | 7 | 163.17 | $8\frac{9}{16}$ | 133.5 | $8\frac{9}{16}$ | 133 | 84.1 | 1.402 | † |
| 79 | 6 | 162 | 6 | 158.63 | 5.8 | 157.75 | 5.8 | 162.5 | 23.76 | .396 | * |
| 80 | 6 | 157.25 | 6 | 158.42 | 5 | 152.83 | 5 | 153 | 54.9 | .915 | * |
| 81 | 6 | 157 | 6 | 158.4 | 4 | 145.2 | 4 | 145 | 69.9 | 1.165 | ‡ |
| 82 | 6 | 157.25 | 6 | 158.33 | 3.5 | 144 | 3.5 | 144 | 71.7 | 1.195 | * |
| 83 | 6 | 157 | 6 | 158.42 | 1 | 134.83 | 1 | 134.5 | 72.2 | 1.203 | † |
| 84 | 5 | 151 | 5 | 151.42 | 4.82 | 150.33 | 4.85 | 151.5 | 21.6 | .36 | * |
| 85 | 5 | 151 | 5 | 152.08 | 4 | 144.92 | 4 | 145.75 | 49.4 | .823 | † |
| 86 | 5 | 151 | 5 | 153.17 | 3 | 142.25 | 3 | 143.75 | 60.6 | 1.01 | † |
| 87 | 5.1 | 151.25 | 5 | 151.92 | 1 | 117.42 | 1 | 117.42 | 63.8 | 1.063 | † |
| 88 | 5 | 151 | 5 | 152.25 | $\frac{9}{16}$ | 127.75 | $\frac{9}{16}$ | 128.5 | 61.2 | 1.02 | † |

* Wet. † Dry. ‡ Nearly dry.

| No. of test. | Steam pressures ($p$) in atmos. abs., and steam temperatures ($t$) in °C. In front of the outflow opening. | | | | Back of the outflow opening. | | | | Outflow volume per Hour. | Outflow volume per Min. | Sight glass. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $p_1$ | $t_1$ | $p_2$ | $t_2$ | $p_3$ | $t_3$ | $p_4$ | $t_4$ | kg. | kg. | |
| 89 | 4 | 141.75 | 4 | 143.25 | 3.8 | 141.67 | 3.8 | 141.5 | 19.5 | .325 | † |
| 90 | 4 | 142.5 | 4 | 143.58 | 3 | 135.17 | 3 | 135 | 42.5 | .709 | * |
| 91 | 4 | 141.75 | 4 | 143.5 | 1 | 123.83 | 1 | 123 | 49.5 | .825 | † |
| 92 | 3 | 132 | 3 | 133.58 | 2.8 | 131.92 | 2.8 | 131.75 | 15.8 | .263 | * |
| 93 | 3 | 133 | 3 | 133.67 | 2.5 | 128.83 | 2.5 | 129 5 | 29.2 | .487 | † |
| 94 | 3 | 132 | 3 | 133.42 | 2 | 122.67 | 2 | 123 | 35.8 | .597 | † |
| 95 | 3.05 | 134 | 3 | 134.83 | 1 | 122.17 | 1 | 122.17 | 38.3 | .638 | † |
| 96 | 3 | 137.5 | 3 | 137.17 | $9\frac{5}{15}$ | 110.58 | $9\frac{5}{15}$ | 110.5 | 37.4 | .623 | † |
| 97 | 2 | 119 5 | 2 | 120 | 1.8 | 117.75 | 1.8 | 118 | 12.2 | .203 | * |
| 98 | 2 | 119.5 | 2 | 120.83 | 1.5 | 114.5 | 1.5 | 115 | 21.4 | .357 | † |
| 99 | 2 | 125.25 | 2 | 125.17 | 1 | 114.5 | 1 | 116 | 24.9 | .415 | † |
| 100 | 2 | 119.5 | 2 | 120.5 | $\frac{9}{15}$ | 87.17 | $\frac{9}{15}$ | 84.5 | 24.9 | .415 | * |
| 101 | 1.3 | 97 | 1.22 | 97.25 | $\frac{10}{15}$ | 94.5 | $\frac{10}{15}$ | 93 | 13.95 | .232 | * |
| 102 | 1 | 97 | 1.2 | 97.83 | $\frac{10}{15}$ | 92.33 | $\frac{10}{15}$ | 92.5 | 16.1 | .268 | * |
| | | | | | ORIFICE SHAPE No. III. | | | | | | |
| 103 | 9 | 172.5 | 9 | 174.17 | 8.8 | 173.25 | 8.8 | 173 | 25.03 | .417 | * |
| 104 | 9 | 171.25 | 9 | 173.4 | 8 | 169.6 | 8 | 169.5 | 59 64 | .994 | * |
| 105 | 9 | 171.75 | 9 | 173.92 | 7 | 165.67 | 7 | 165.5 | 82.7 | 1.378 | * |
| 106 | 9 | 172.5 | 9 | 174 | 6 | 161 | 6 | 161 | 94.8 | 1.58 | * |
| 107 | 9 | 172.5 | 9 | 174 | 5 | 157.17 | 5 | 157.5 | 98.3 | 1.638 | * |
| 108 | 9 | 172.5 | 9 | 173.83 | 4 | 154 | 4 | 154 | 101.2 | 1.687 | * |
| 109 | 9 | 172.5 | 9 | 173.5 | $\frac{9}{15}$ | 139.67 | $\frac{9}{15}$ | 139.5 | 101.3 | 1.688 | † |
| 110 | 8 | 168.5 | 8 | 169.42 | 7.8 | 168.42 | 7.8 | 168.5 | 26.3 | .438 | * |
| 111 | 8 | 167.5 | 8 | 169.17 | $\frac{10}{15}$ | 138.08 | $\frac{10}{15}$ | 138.25 | 91.6 | 1.527 | † |
| 112 | 7 | 162.25 | 7 | 164.17 | 6.8 | 163.17 | 6.8 | 162.75 | 23.3 | .388 | ‡ |
| 113 | 7 | 162.5 | 7 | 163.83 | 6.5 | 161.58 | 6.5 | 162 | 37.2 | .62 | * |
| 114 | 7 | 165.5 | 7 | 164 | 6 | 159.17 | 6 | 160 | 53.3 | .888 | * |
| 115 | 7 | 161.5 | 7 | 162.83 | 5 | 153.33 | 5 | 153.5 | 69.4 | 1.157 | * |
| 116 | 7 | 162 | 7 | 163.83 | 4 | 148.5 | 4 | 148.5 | 76.5 | 1.275 | * |
| 117 | 7 | 162.25 | 7 | 163.5 | 3 | 143.33 | 3 | 142.5 | 80 | 1.333 | ‡ |
| 118 | 7 | 162 | 7 | 163.83 | $\frac{9}{15}$ | 132.83 | $\frac{9}{15}$ | 132 | 79.7 | 1.328 | † |
| 119 | 6 | 155.5 | 6 | 157.83 | $\frac{9}{15}$ | 130.75 | $\frac{9}{15}$ | 131 | 69.4 | 1.157 | † |
| 120 | 5 | 150 | 5 | 151.08 | 4.8 | 150.08 | 4.8 | 150.25 | 17.4 | .29 | * |
| 121 | 5 | 150 | 5 | 151 | 4 | 144.75 | 4 | 145 | 45.1 | .752 | * |
| 122 | 5 | 150 | 5 | 151 | 3 | 137 | 3 | 137 | 54.1 | .902 | * |
| 123 | 5 | 151 | 5 | 151.75 | 2.6 | 135.92 | 2.6 | 136 | 57.6 | .96 | * |
| 124 | 5 | 150 | 5 | 151.33 | 1.8 | 131.33 | 1.6 | 129.5 | 58 | .967 | † |
| 125 | 5 | 150.25 | 5 | 151.08 | $\frac{12}{15}$ | 126.75 | $\frac{12}{15}$ | 127 | 58 | .967 | † |
| 126 | 4 | 144 | 4 | 145.17 | $\frac{12}{15}$ | 126.5 | $\frac{12}{15}$ | 123 | 47.1 | .785 | † |
| 127 | 3 | 134 | 3 | 134.25 | 2.8 | 131.25 | 2.8 | 131.5 | 13.6 | .227 | * |
| 128 | 3 | 131 | 3 | 133.4 | 2 | 122.8 | 2 | 122.5 | 32.04 | .534 | * |
| 129 | 3 | 132.5 | 3 | 132.83 | 1 | 112.67 | 1 | 112 | 35.2 | .587 | † |
| 130 | 3 | 134.5 | 3 | 134.67 | $\frac{12}{15}$ | 117.92 | $\frac{12}{15}$ | 119.25 | 35.7 | .595 | † |
| 131 | 2 | 119.5 | 2 | 119.67 | 1.8 | 118.33 | 1.8 | 118 | 9.6 | .16 | * |
| 132 | 2 | 118.5 | 2 | 119.83 | 1 | 106.33 | 1 | 106.5 | 22 1 | .368 | * |
| 133 | 2 | 121 | 2 | 119.67 | $\frac{9}{15}$ | 102 | $\frac{9}{15}$ | 103 | 23.4 | .39 | † |
| 134 | 1.2 | 113.25 | 1.2 | 109.92 | $\frac{10}{15}$ | 102.83 | $\frac{10}{15}$ | 106 | 15.5 | .258 | † |

* Wet. † Dry. ‡ Nearly dry. ‡ Moist.

| No. of test. | Steam pressures ($p$) in atmos. abs., and steam temperatures ($t$) in °C. | | | | | | | | Outflow volume per | | Sight glass. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | In front of the outflow opening. | | | | Back of the outflow opening. | | | | Hour. | Min. | |
| | $p_1$ | $t_1$ | $p_2$ | $t_2$ | $p_3$ | $t_3$ | $p_4$ | $t_4$ | kg. | kg. | |
| **Orifice Shape No. IV.** | | | | | | | | | | | |
| 135 | 9 | 173.5 | 9 | 174.25 | 8.8 | 173.17 | 8.8 | 173.5 | 32.5 | .542 | * |
| 136 | 9 | 173 | 9 | 174 | 8.5 | 171.58 | 8.5 | 171.75 | 57.2 | .953 | * |
| 137 | 9 | 173 | 9 | 173.83 | 8 | 170 | 8 | 170.5 | 77.5 | 1.292 | * |
| 138 | 9 | 173 | 9 | 173.92 | 7 | 164.67 | 7 | 165 | 90.7 | 1.512 | * |
| 139 | 9 | 173.5 | 9 | 173.92 | 6 | 160 | 6 | 160 | 91.3 | 1.522 | ‡ |
| 140 | 9 | 173 | 9 | 174.17 | 5 | 154.92 | 5 | 154.5 | 91.2 | 1.520 | * |
| 141 | 9 | 172.5 | 9 | 173.75 | 1 | 138.33 | 1 | 135. | 91.3 | 1.522 | † |
| 142 | 8 | 168 | 8 | 169.33 | 7.8 | 168.17 | 7.8 | 168 | 32.9 | .548 | * |
| 143 | 8 | 168 | 8 | 169 | 7.5 | 167 | 7.5 | 167 | 53.3 | .888 | * |
| 144 | 8 | 169 | 8 | 169.42 | 7 | 164.5 | 7 | 164.75 | 72.5 | 1.208 | * |
| 145 | 8 | 169 | 8 | 168.67 | 6 | 159 | 6 | 159 | 81.5 | 1.358 | * |
| 146 | 8 | 168 | 8 | 169.17 | 5 | 154 | 5 | 154 | 81.4 | 1.357 | * |
| 147 | 8 | 168 | 8 | 169.5 | 1 | 136.5 | 1 | 134.5 | 82.4 | 1.373 | † |
| 148 | 7 | 162.5 | 7 | 164.33 | 6.8 | 163.08 | 6.8 | 163 | 30.9 | .515 | * |
| 149 | 7 | 163.5 | 7 | 164.17 | 6.5 | 161.33 | 6.5 | 162 | 50.7 | .845 | * |
| 150 | 7 | 162.5 | 7 | 163.92 | 6 | 158.83 | 6 | 158.5 | 65.5 | 1.092 | * |
| 151 | 7 | 162.5 | 7 | 163.75 | 5 | 153.58 | 5 | 153.75 | 72 | 1.2 | * |
| 152 | 7 | 163 | 7 | 164 | 1 | 134.58 | 1 | 131 | 72.7 | 1.212 | † |
| 153 | 5 | 151 | 5 | 151.75 | 4.8 | 150.5 | 4.8 | 150.75 | 20.9 | .348 | * |
| 154 | 5 | 149.5 | 5 | 151.42 | 4.5 | 148 | 4.5 | 147.5 | 39.3 | .655 | * |
| 155 | 5 | 150 | 5 | 151.08 | 4 | 144.17 | 4 | 144 | 50.5 | .842 | * |
| 156 | 5 | 150.5 | 5 | 151.33 | 3 | 137.17 | 3 | 137 | 51.5 | .858 | * |
| 157 | 5 | 151 | 5 | 151.5 | 1 | 130.33 | 1 | 131 | 51.2 | .853 | † |
| 158 | 3 | 133 | 3 | 134.33 | 2.8 | 132.5 | 2.8 | 132.5 | 17.8 | .297 | § |
| 159 | 3 | 132.5 | 3 | 133.08 | 2.5 | 128.67 | 2.5 | 129 | 29.2 | .487 | § |
| 160 | 3 | 132 | 3 | 133.5 | 2 | 122.42 | 2 | 122.25 | 31.2 | .52 | § |
| 161 | 3 | 133.5 | 3 | 134.33 | 1 | 122.67 | 1 | 124.5 | 32.1 | .535 | † |
| 162 | 2 | 119.5 | 2 | 119 | 1.8 | 117.67 | 1.8 | 118 | 14.1 | .235 | § |
| 163 | 2 | 118 | 2 | 118.83 | 1.5 | 114 | 1.5 | 113.5 | 19.9 | .332 | § |
| 164 | 2 | 119.5 | 2 | 120.17 | 1 | 104 | 1 | 104 | 20.6 | .343 | § |
| **Orifice Shape No. V.** | | | | | | | | | | | |
| 165 | 9 | 173 | 9 | 174 | 8.8 | 172.92 | 8.8 | 173 | 49.7 | .828 | * |
| 166 | 9 | 173 | 9 | 174.08 | 8.5 | 171.42 | 8.5 | 171.25 | 88.8 | 1.48 | * |
| 167 | 9 | 172.5 | 9 | 174.4 | 8 | 169 | 8 | 168.5 | 104.6 | 1.743 | * |
| 168 | 9 | 173 | 9 | 174 | 7 | 164.17 | 7 | 164 | 105.4 | 1.757 | * |
| 169 | 9 | 173.5 | 9 | 174.08 | 6 | 159.5 | 6 | 159.5 | 105.6 | 1.76 | * |
| 170 | 9 | 173 | 9 | 173.92 | 1 | 143.5 | 1 | 144 | 105.8 | 1.763 | † |
| 171 | 7 | 163 | 7 | 164.08 | 6.8 | 162.67 | 6.8 | 162.75 | 46.7 | .778 | * |
| 172 | 7 | 163 | 7 | 164.08 | 6.5 | 160.83 | 6.5 | 160.75 | 77 | 1.283 | * |

* Wet. † Dry. ‡ Nearly dry. § Moist.

| No. of test. | Steam pressures ($p$) in atmos. abs., and steam temperatures ($t$) in °C'. In front of the outflow opening. | | | | Back of the outflow opening. | | | | Outflow volume per Hour. | Outflow volume per Min. | Sight glass. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $p_1$ | $t_1$ | $p_2$ | $t_2$ | $p_3$ | $t_3$ | $p_4$ | $t_4$ | kg. | kg. | |
| 173 | 7 | 162.5 | 7 | 163.67 | 6 | 158.17 | 6 | 158 | 83.4 | 1.39 | * |
| 174 | 7 | 163 | 7 | 163.92 | 5 | 153.08 | 5 | 153 | 82.8 | 1.38 | * |
| 175 | 7 | 163 | 7 | 163.83 | 1 | 136.83 | 1 | 136.5 | 83.1 | 1.385 | † |
| 176 | 5 | 150 | 5 | 151.58 | 4.8 | 150.33 | 4.8 | 150 | 35.5 | .592 | * |
| 177 | 5 | 150 | 5 | 151.5 | 4.5 | 148.17 | 4.5 | 147.5 | 59.9 | .998 | * |
| 178 | 5 | 150 | 5 | 151.42 | 4 | 144.25 | 4 | 144.75 | 61 | 1.017 | * |
| 179 | 5 | 152 | 5 | 152.33 | 1 | 128.92 | 1 | 128.5 | 60.6 | 1.01 | † |
| 180 | 3 | 133.5 | 3 | 133.83 | 2.8 | 131.58 | 2.8 | 131.75 | 29.9 | .498 | * |
| 181 | 3 | 132.5 | 3 | 133.25 | 2.5 | 128.33 | 2.5 | 128.5 | 36.8 | .613 | * |
| 182 | 3 | 131.5 | 3 | 133 | 1 | 109.17 | 1 | 108.5 | 37 | .617 | † |
| 183 | 2 | 121 | 2 | 120.83 | 1.8 | 119.17 | 1.8 | 120 | 21.4 | .357 | * |
| 184 | 2 | 119 | 2 | 119.67 | 1.5 | 114.67 | 1.5 | 115 | 24.2 | .403 | * |
| 185 | 2 | 118 | 2 | 119.33 | 1 | 104 | 1 | 104 | 24.1 | .402 | * |
| | | | | | ORIFICE SHAPE No. VI. | | | | | | |
| 186 | 9 | 173 | 9 | 173.92 | 8.8 | 172.75 | 8.8 | 173 | 20.6 | .343 | * |
| 187 | 9 | 172.5 | 9 | 173.83 | 8.5 | 171 | 8.5 | 170.5 | 41.8 | .697 | * |
| 188 | 9 | 173.5 | 9 | 174.03 | 8 | 169.33 | 8 | 169.5 | 61.9 | 1.032 | * |
| 189 | 9 | 173 | 9 | 174.7 | 7 | 165.2 | 7 | 165 | 83.4 | 1.39 | * |
| 190 | 9 | 173 | 9 | 174 33 | 6 | 159.92 | 6 | 160 | 94.6 | 1.577 | † |
| 191 | 9 | 173 | 9 | 174.08 | 5 | 155.75 | 5 | 155.5 | 99.4 | 1.657 | * |
| 192 | 9 | 173 | 9 | 174 | 4 | 151.08 | 4 | 150 | 101.1 | 1.685 | * |
| 193 | 9 | 173 | 9 | 174.78 | 1 | 141.71 | 1 | 141.5 | 101.23 | 1.687 | † |
| 194 | 7 | 162.5 | 7 | 164 | 6.8 | 162.67 | 6.8 | 162.25 | 20.4 | .34 | * |
| 195 | 7 | 163 | 7 | 164.33 | 6.5 | 161.33 | 6.5 | 161 | 37.2 | .62 | * |
| 196 | 7 | 163 | 7 | 163.42 | 6 | 157.83 | 6 | 157.5 | 53.7 | .895 | * |
| 197 | 7 | 164 | 7 | 164.42 | 5 | 153.75 | 5 | 154.25 | 71.3 | 1.188 | * |
| 198 | 7 | 163.5 | 7 | 164.08 | 4 | 147.25 | 4 | 147.5 | 77.9 | 1.298 | † |
| 199 | 7 | 163 | 7 | 163.58 | 3 | 144.92 | 3 | 145 | 79.9 | 1.332 | ‡ |
| 200 | 7 | 163 | 7 | 164.17 | 1 | 138.25 | 1 | 138.5 | 79.8 | 1.33 | † |
| 201 | 5 | 151.5 | 5 | 151.5 | 4.8 | 150.08 | 4.8 | 151 | 16.1 | .268 | * |
| 202 | 5 | 149.5 | 5 | 150.5 | 4.5 | 147.25 | 4.5 | 147.5 | 31 | .517 | * |
| 203 | 5 | 151 | 5 | 151.08 | 4 | 144.08 | 4 | 145 | 46.2 | .77 | * |
| 204 | 5 | 151.5 | 5 | 151.92 | 3 | 137.08 | 3 | 137 | 56.4 | .94 | * |
| 205 | 5 | 150.5 | 5 | 151.42 | 2 | 132.33 | 2 | 132 | 58.3 | .972 | * |
| 206 | 5 | 150 | 5 | 150.67 | 1 | 128 | 1 | 128 | 57.4 | .957 | † |
| 207 | 3 | 132 | 3 | 133.25 | 2.8 | 132.17 | 2.8 | 131.25 | 13.9 | .232 | * |
| 208 | 3 | 132.5 | 3 | 133.08 | 2.5 | 129.17 | 2.5 | 130 | 24.9 | .415 | * |
| 209 | 3 | 134 | 3 | 134 | 2 | 123.17 | 2 | 124 | 32.9 | .548 | * |
| 210 | 3 | 133 | 3 | 135 | 1 | 119.67 | 1 | 121 | 35 | .583 | † |

* Wet. † Dry. ‡ Nearly dry.

| No. of test. | Steam pressures ($p$) in atmos. abs., and steam temperatures ($t$) in °C. In front of the outflow opening. | | | | Back of the outflow opening. | | | | Outflow volume per Hour. | Outflow volume per Min. | Sight glass. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $p_1$ | $t_1$ | $p_2$ | $t_2$ | $p_3$ | $t_3$ | $p_4$ | $t_4$ | kg. | kg. | |
| | | | | | ORIFICE SHAPE No. VII. | | | | | | |
| 211 | 9 | 172 | 9 | 172.83 | 8.8 | 172.5 | 8.8 | 172.25 | 19 | .317 | * |
| 212 | 9 | 172 | 9 | 173.33 | 8.5 | 171.17 | 8.5 | 171 | 41.3 | .688 | * |
| 213 | 9 | 172 | 9 | 173.5 | 8 | 169.17 | 8 | 169 | 63.9 | 1.065 | * |
| 214 | 9 | 172.5 | 9 | 173.83 | 7 | 165 | 7 | 165 | 85.7 | 1.42 | * |
| 215 | 9 | 172.5 | 9 | 173.5 | 6 | 160.25 | 6 | 160 | 96.1 | 1.602 | * |
| 216 | 9 | 172.5 | 9 | 173 | 5 | 154.67 | 5 | 155 | 100.4 | 1.673 | * |
| 217 | 9 | 172.5 | 9 | 173.33 | 1 | 138.58 | 1 | 136.5 | 101.9 | 1.698 | † |
| 218 | 7 | 164 | 7 | 163.67 | 6.8 | 162.42 | 6.8 | 162 | 17.3 | .288 | * |
| 219 | 7 | 162.5 | 7 | 163.58 | 6.5 | 160.67 | 6.5 | 162 | 38.3 | .638 | * |
| 220 | 7 | 163 | 7 | 163.83 | 6 | 158.67 | 6 | 158.5 | 57.1 | .952 | * |
| 221 | 7 | 162 | 7 | 163.83 | 5 | 153.25 | 5 | 153 | 72.6 | 1.21 | * |
| 222 | 7 | 163 | 7 | 164.17 | 4 | 147.33 | 4 | 147.5 | 79.3 | 1.322 | * |
| 223 | 7 | 163 | 7 | 164 | 3 | 140.83 | 3 | 141 | 80.8 | 1.347 | † |
| 224 | 7 | 162 | 7 | 163.83 | 1 | 138 | 1 | 138 | 81.2 | 1.353 | * |
| 225 | 5 | 150.5 | 5 | 151.58 | 4.8 | 148.17 | 4.8 | 148 | 32.8 | .547 | * |
| 226 | 5 | 150.5 | 5 | 151.83 | 4.5 | 150.92 | 4.5 | 150.75 | 16.3 | .272 | * |
| 227 | 5 | 150.5 | 5 | 151.17 | 4 | 144.17 | 4 | 144.5 | 46 | .767 | * |
| 228 | 5 | 149.5 | 5 | 150.67 | 3 | 136.67 | 3 | 136.5 | 55.8 | .93 | * |
| 229 | 5 | 149.5 | 5 | 150.83 | 2 | 128.33 | 2 | 129 | 58.7 | .978 | † |
| 230 | 5 | 152 | 5 | 152 | 1 | 132 | 1 | 133 | 58 | .967 | † |
| 231 | 3 | 135.5 | 3 | 134.5 | 2.8 | 132 | 2.8 | 133 | 13.5 | .225 | * |
| 232 | 3 | 131 | 3 | 132.5 | 2.5 | 128.08 | 2.5 | 128 | 24.4 | .407 | * |
| 233 | 3 | 132 | 3 | 132.75 | 2 | 122.08 | 2 | 122 | 33.2 | .553 | * |
| 234 | 3 | 132 | 3 | 131.25 | 1 | 99.67 | 1 | 100 | 33.5 | .558 | † |
| | | | | | ORIFICE SHAPE No. VIII. | | | | | | |
| 235 | 9 | 172.5 | 9 | 173.83 | 8.8 | 172.75 | 8.8 | 172.5 | 151.2 | 2.52 | * |
| 236 | 9 | 173 | 9 | 173.83 | 8.5 | 171.5 | 8.5 | 172 | 319.4 | 5.323 | * |
| 237 | 9 | 173 | 9 | 174 | 8 | 169 | 8 | 169 | 497.1 | 8.285 | * |
| 238 | 9 | 173 | 9 | 173.75 | 7 | 165.33 | 7 | 165 | 693.3 | 11.555 | * |
| 239 | 9 | 173 | 9 | 173.92 | 6 | 162.83 | 6 | 162.5 | 788.8 | 13 147 | ‡ |
| 240 | 9 | 166.5 | 9 | 172.17 | 5 | 158.67 | 5 | 159 | 825.8 | 13.763 | † |
| 241 | 9 | 172 | 9 | 174.08 | 2 | 146.33 | 2 | 146.5 | 837.1 | 13 952 | † |
| 242 | 9 | 172.5 | 9 | 173.83 | 1 | 146.17 | 1 | 145.75 | 845.7 | 14.095 | † |
| 243 | 8 | 168.5 | 8 | 169.5 | 1 | 143.1 | 1 | 143.5 | 750.6 | 12 51 | † |
| 244 | 7 | 163 | 7 | 164 | 6.8 | 162.58 | 6.8 | 162.5 | 174.1 | 2.902 | * |
| 245 | 7 | 162.5 | 7 | 163.8 | 6.5 | 160.9 | 6.5 | 161 | 309.3 | 5.155 | * |
| 246 | 7 | 163 | 7 | 164 | 6 | 158 | 6 | 158 | 440 | 7.333 | * |
| 247 | 7 | 162.5 | 7 | 163.5 | 5 | 154 | 5 | 154 | 580.7 | 9.678 | * |
| 248 | 7 | 163 | 7 | 164 | 4 | 150.5 | 4 | 150 | 652.9 | 10.882 | † |
| 249 | 7 | 163 | 7 | 164 | 1 | 139 | 1 | 152 | 665.4 | 11.09 | † |
| 250 | 6 | 157 | 6 | 158.2 | 1 | 137.2 | 1 | 137 | 566.1 | 9.435 | † |
| 251 | 6 | 157 | 6 | 158 | 1 | 136.83 | 1 | 137 | 562.2 | 9.37 | † |
| 252 | 5 | 151 | 5 | 151.7 | 4.8 | 149.8 | 4.8 | 150 | 160.8 | 2.68 | * |
| 253 | 5 | 150 | 5 | 150.9 | 4.5 | 147.5 | 4.5 | 147.25 | 258.6 | 4.31 | * |
| 254 | 5 | 150 | 5 | 151.08 | 4 | 144.5 | 4 | 144 | 378.2 | 6.303 | * |
| 255 | 5 | 151 | 5 | 151.67 | 3 | 140.58 | 3 | 140.5 | 473.3 | 7.888 | † |
| 256 | 5 | 150.5 | 5 | 151.17 | 1 | 134 | 1 | 134 | 476.6 | 7.943 | † |
| 257 | 3 | 132.5 | 3 | 133.33 | 2.8 | 131.58 | 2.8 | 131.5 | 119.9 | 1.998 | * |
| 258 | 3 | 133 | 3 | 133.58 | 2.5 | 128.67 | 2.5 | 129 | 202.4 | 3.373 | * |
| 259 | 3 | 132 | 3 | 133.5 | 2 | 125.67 | 2 | 125 | 268.2 | 4 47 | * |
| 260 | 3 | 132.5 | 3 | 133.42 | 1 | 122.17 | 1 | 122.5 | 294.6 | 4.91 | † |

* Wet. † Dry. ‡ Nearly dry.

RESULTS OF EXPERIMENTS.

To give a clear idea of the conformity to a fixed law by the test results for one and the same outflow opening for varying conditions of outflow, graphical representation has been resorted to.

In Fig. 6 to 13 the pressure differences between outflow and receiving vessel are represented by the abscissæ, the observed average outflow volumes per minute by the ordinates.

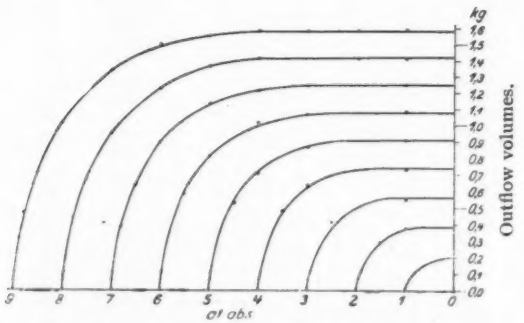


**Fig. 6.**—ORIFICE SHAPE I [$F = 22.9$ sq. mm.]

If the points of the successive ordinates, representing the outflow volumes for equal pressures in the outflow vessel, are connected with one another or if curves are drawn closely following these points, then these graphical representations of the test results for the eight different shaped openings investigated will show clearly the following connection between outflow volumes and outflow velocities obtained under varying conditions.

(1) At constant pressure in the outflow vessel and increasing pressure differences, under which the outflow results, the amount of steam $G$ flowing out in a unit of time increases until a certain reduction in pressure in the receiving vessel; upon further reduction of the pressure in the latter, even down to a vacuum, the volume of steam flowing over remains constant ($G_{max.}$)

The pressure in the receiving vessel, under which the outflow volume remains unvaried, corresponds to the pressure $p$ in the plane of the orifice already established in the theory for the out-

flow of steam; its relation, according to Zeuner ("Technische Thermodynamik," Vol. II, p. 163), to the pressure $p_1$, in the outflow vessel is: $\frac{p}{p_1} = 0.5770$.

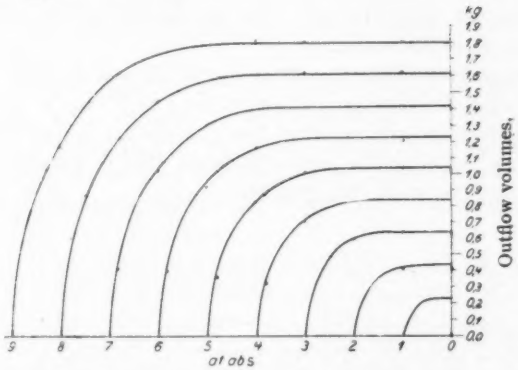


**Fig. 7.**—ORIFICE SHAPE II [$F$=22.9 sq. mm.]

(2) The greatest steam volumes ($G_{max}$) which can flow out of a given opening for different steam pressures in the outflow vessel are nearly proportional to the specific gravity ($\gamma$) of the steam in the outflow vessel; therefore

$$\frac{G_{max}}{\gamma} = \text{constant} = V_{max},$$

*i. e.*, the maximum steam volume flowing out of the outflow vessel is nearly constant and the same for all pressures.

(3) The influence of the shape of the orifice on the outflow volume is varied, depending upon whether the pressure in the receiving vessel is above or below the pressure in the plane of the orifice.

By way of comparison, in Fig. 14 are shown the curves of the outflow volumes for eight atmospheres initial pressure for the eight different shaped orifices investigated.

They show that the maximum outflow volumes are affected most by contraction, less by friction, and least by divergence of the jet.

The Laval nozzle, IV, delivered the least steam volume; then follow the circular openings VIII and I, of which I produced proportionately less contraction than the larger opening VIII, which at 9-fold area only delivered an 8.86-fold steam volume. The greatest steam volume was passed by orifice II having rounded-off edges inside.

A comparison of the results of I with IV and II with V show the peculiar phenomena that with the Laval nozzle the maximum outflow volume becomes less than for the free orifice of the same area; whereas for pressures below that in the plane of the orifice the reverse of this obtains.

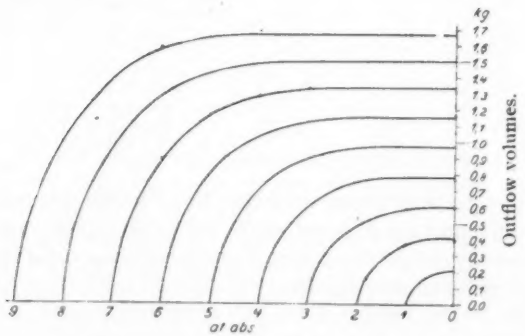


**Fig. 8.**—ORIFICE SHAPE III [$F$=22.9 sq. mm.]

The latter fact, no doubt, is thereby explained that, owing to the divergence of the walls of the nozzle a suction action is produced around the outflowing steam jet, and with it a drop in pressure, which increases the pressure in the outflowing steam jet, and by that causes an earlier setting in of the pressure in the plane of the orifice than conditioned for maximum steam volume.

Surprising also is the result of the test series III and VII that, in spite of the friction in the long nozzle attachment, the outflow volume was above that for the free opening. The explanation for this phenomena is to be found in suction action of the conical Laval nozzle, being noticeable here in a lessened degree.

The conclusions to be drawn from the agreement of test series

III and VI, compared with VII, are that, on the one hand, the curvature of the port counteracts the slight advantage arising from the suction action in the straight nozzle, and that, on the other hand, the divergence of the steam jet back of the outflow opening produces no practical significant change in the outflow conditions.

The maximum outflow volumes of the orifices II and V arise as a result of the removal of the contraction; by that the Laval nozzle, V, appears less favorable than the free opening in a ratio depending on the friction produced by the steam jet in the nozzle space, and, probably, also on the losses due to eddying.

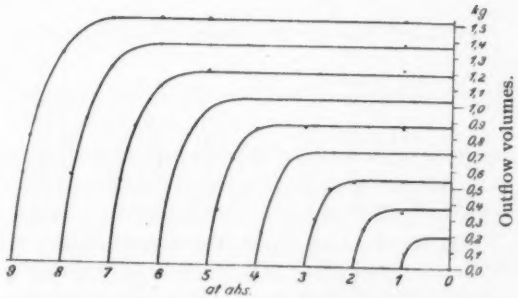


**Fig. 9.**—ORIFICE SHAPE IV [$F$=22.9 sq. mm.]

A short reference may now be made, to show to what extent the observed outflow volumes agree with those values, calculated from the usual outflow formulæ. According to Zeuner ("Technische Thermodynamik," Vol. II, p. 162), the outflow volume $G$ is determined approximately from—

$$G = aF\sqrt{\frac{2gk}{k-1}\cdot\frac{p_1}{v_1}\left[\left(\frac{p_2}{p_1}\right)^{\frac{2}{k}} - \left(\frac{p_2}{p_1}\right)^{\frac{k+1}{k}}\right]}$$

in which

$F$ = area of the orifice;
$k$ = 1.135;
$p_1$ = pressure in the outflow vessel;
$p_2$ = pressure in the receiving vessel;
$v_1$ = specific steam volume per pressure $p_1$;
$a$ = coefficient for outflow.

Taking $\alpha = 1$, there results for the circular outflow orifice exactly those steam volumes which were observed during the tests for the funnel-shaped orifice II, having rounded-off edges.

As an example, Fig. 14 shows for the points prominently indicated on the experimentally established curve II a complete agreement of the calculated values with the actual ones.

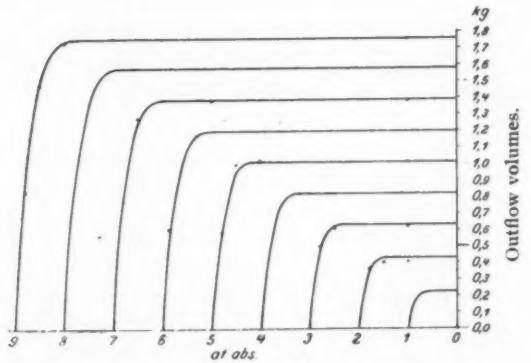


**Fig. 10.**—ORIFICE SHAPE V [$F$=22.9 sq. mm.]

From a comparison of all the curves for the outflow volumes it may be seen that only those referring to the Laval nozzle show remarkable variation, while for the other orifice shapes agreement with the laws prevail. For the latter, therefore, the outflow volumes can be calculated from the Zeuner formula for outflow, if the coefficient of outflow concerning an orifice shape is known. A closer inspection of the present test results shows that these coefficients do depend not only on the shape of the orifice but also on the increase in pressure and on the ratio $\frac{p_1}{p_2}$.

As an example, in the following table are given values for the coefficients of contraction, $\alpha$ and $\alpha'$, for a cylindrical and a rectangular orifice, referred to the steam volumes delivered by a funnel-shaped circular orifice for $p_1 = 9.0$ atmospheres absolute in the outflow vessel.

| Orifice. | Pressure in the receiving vessel $= p_2$ atmos. absolute. | | | | | | |
|---|---|---|---|---|---|---|---|
| | 8.8 | 8.5 | 8.0 | 7.0 | 6.0 | 5.5 | 5.197 (Pressure in plane of orifice.) |
| Cylindrical orifice I, $\alpha =$ | 0.705 | 0.78 | 0.805 | 0.846 | 0.855 | 0.868 | 0.88 |
| Rectangular orifice III, $\alpha' =$ | 0.71 | 0.795 | 0.83 | 0.896 | 0.91 | 0.925 | 0.933 |
| $\frac{p_2}{p_1} =$ | 0.977 | 0.944 | 0.888 | 0.777 | 0.666 | 0.611 | 0.5774 |

The variability of the co-efficients of contraction as shown in the foregoing table can be expressed, sufficiently accurately for all practical purposes, by the following relation:

$$\text{for cylindrical orifices I, } \alpha = 1.043 - 0.285\frac{p_2}{p_1},$$

$$\text{for rectangular orifices III, } \alpha' = 1.098 - 0.285\frac{p_2}{p_1}.$$

As, according to this, the rectangular slits show more favorable co-efficients of contraction than circular ones of equal area, it follows that *long and narrow steam ports produce less contraction than wide and short ones.*

The close agreement existing in the behavior of orifices III and VI permits the further conclusion that the steam volumes flowing through long and more or less curved ports, as on slide-valve engines, are not materially affected. Therefore the fric-

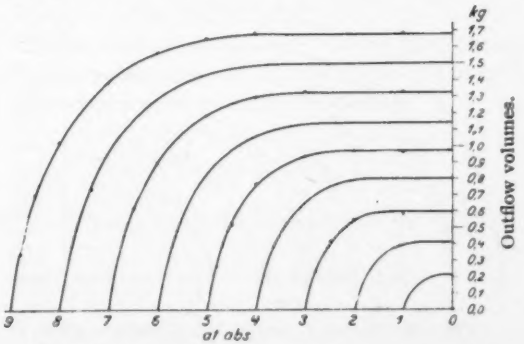


**Fig. 11.**—ORIFICE SHAPE VI [$F$=22.9 sq. mm.]

tion in the port produces only a subordinate influence on the flow procedure of the steam.

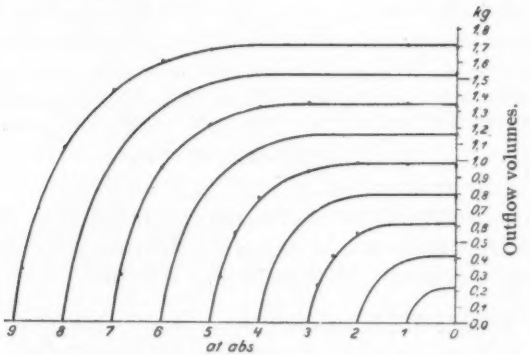


**Fig. 12.**—ORIFICE SHAPE VII [$F$=22.9 sq. mm.]

With special reference to Fig. 14 attention must yet be directed to the perceptible *reduction* of the maximum outflow volumes on the one hand, produced by both cases of the Laval nozzle attachments to the orifice shapes I and II, as compared with the free discharge, but, on the other hand, the maximum outflow volumes were obtained with actually lower pressures.

Therefore, for pressures in the receiving vessel which are above the critical ones, the outflow volumes of the Laval nozzle

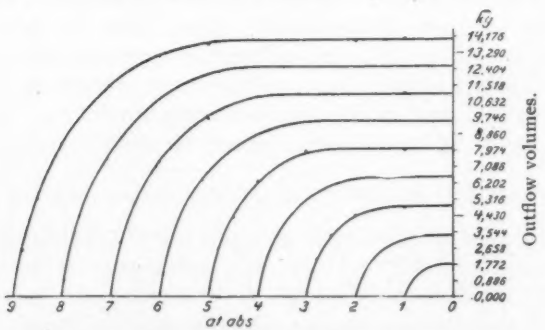


**Fig. 13.**—ORIFICE SHAPE VII [$F$=9×22.9 mm.]

are not in accord with the calculated results of the Zeuner formula for outflow. The *maximum outflow volumes* for the Laval nozzle IV and V are already attained at a pressure ratio of about 0.75 and 0.86, respectively, whilst for the rounded-off outflow orifice, when discharging free, the critical pressure ratio is to be taken at 6.5774, and for the others still less. For the conical nozzles supplementary tests are yet to be made to obtain a proper basis for the correct outflow formula.

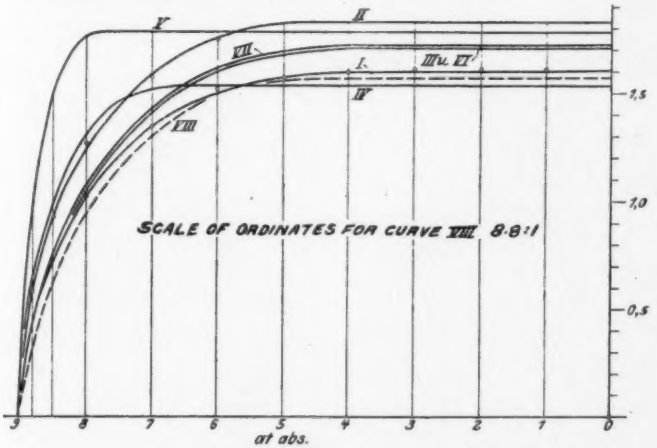


Fig. 14.

THE OUTFLOW VELOCITY.

For the circular orifice having rounded-off edges, the outflow velocity $w$ in the receiving vessel in the plane of the orifice is calculated according to Zeuner from the formula

$$w = \sqrt{\frac{2gk}{k-1} p_1 v_1 \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{k}{k-1}}\right]}$$

but which is only valid up to the critical pressure

$$p_m = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} p_1 = 0.5774\, p_1$$

in the plane of the orifice.

For lower pressures $p_2$ in the receiving vessel than $p_m$ the velocity remains invariable.

The maximum outflow velocity is then determined from the formula

$$w_{max} = \sqrt{\frac{2gk}{k-1} p_1 v_1 \left[1 - 0.5774^{\frac{k-1}{k}}\right]} = 3.23\sqrt{p_1 v_1}.$$

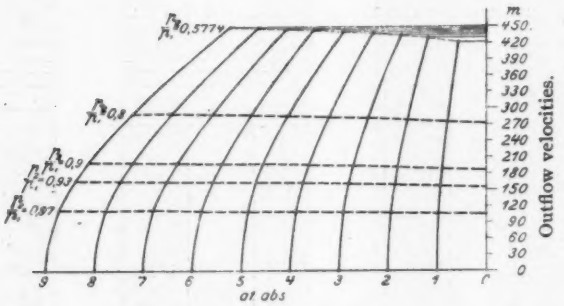


**Fig. 15.**—ORIFICE FORM II.

Accordingly $w_{max}$ shows but small differences for the various pressures $p_1$, the product $p_1 v_1$ varying but slightly, as the following series of figures and Fig. 15 will show.

| $p_1 =$ | 1 | 2 | 4 | 6 | 8 | 10 | 15 | atmos. abs. |
|---|---|---|---|---|---|---|---|---|
| $w_{max} =$ | 422 | 433 | 440 | 445 | 449 | 452 | 458 | m. per sec. |

The fact that above the critical pressure the outflow volume, and therefore the outflow velocity, no longer increases, has also a connection with the appearance of waves in a steam jet *.

The photographs of the steam jets, Fig. 16, † where the critical pressure in the plane of the orifice has set in, show clearly this wave motion.

* A searching investigation on this can be found in the two publications: On the outflow phenomena of permanent gases, by Dr. R. Emden, Leipzig, 1899, J. A. Barth; and The outflow phenomena of steam, by Paul Emden, Munich, 1903, R. Oldenbourg.

† These photographs were taken by me in the fall of 1899.

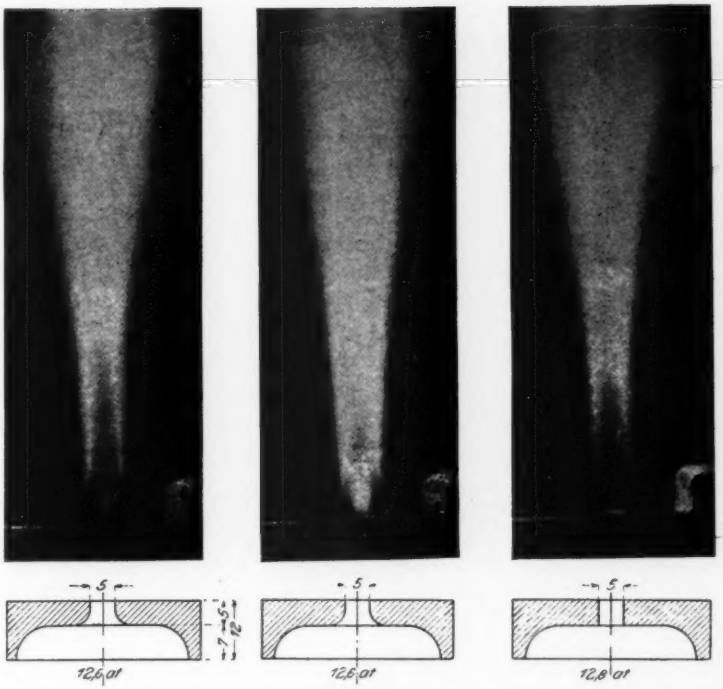


Fig. 16.

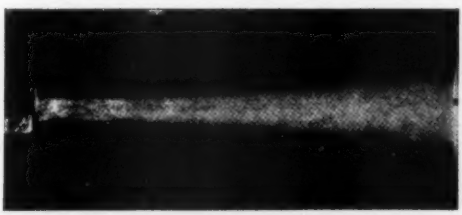

Fig. 19.

From the Zeuner formula for outflow the following laws may yet be deduced which have been verified by the experiments:

Below the maximum the outflow velocities for *equal pressure ratios are nearly constant.* The corresponding points of the curve lie approximately on lines parallel to the axis of abscissa. See Fig. 15. Consequently it also follows that the ends of the co-ordinate points of equal pressure ratios corresponding to the steam volumes below the maximum very nearly lie on lines which pass through the point *O* of the diagram, as shown in Fig. 17. Variations from straight lines in Figs. 15 and 17 are present, inasmuch as the product $p_1 v_1$ for increasing pressures does not remain constant, but is somewhat increased.

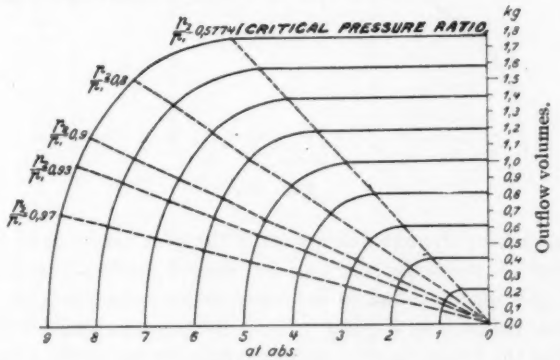


**Fig. 17.**

For approximate calculations the outflow velocity, above the critical pressure in the plane of the orifice, can be determined with sufficient accuracy from the following empirical relation:

$$w = 1{,}000 - 900\,\frac{p_2}{p_1}$$

In Fig. 18 are shown graphically the transitions of the outflow velocities to their greatest value for the orifice shapes investigated for a pressure of 9 atmospheres.

According to this, the greatest value for the outflow velocity is attained most quickly with the Laval nozzle having the edges

rounded off on the admission side; as second best is the behavior of the Laval nozzle having square edges on the inlet side; then follows the circular opening with free discharge and rounded-off edges, while for the one having square edges the transition to the greatest velocity sets in latest of all; between the latter two are the velocity curves for the rectangular orifice shapes with and without nozzle attachments.

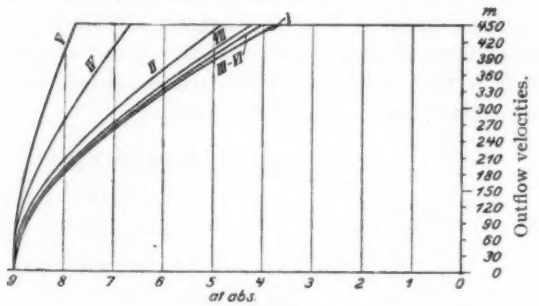


Fig. 18.

Concerning the absolute values of the greatest velocity for the outflow of steam for the various shaped orifices investigated, reference might be had to the comparative representation of the outflow volumes in Fig. 14. From this representation it follows that, for the Laval nozzle having rounded edges on the admission side, the greatest outflow volume and therewith also the greatest outflow velocity is less than for the free opening; for the inlet area having square edges the Laval nozzle generally delivers the least maximum value of the outflow volume and thereby also the least maximum velocity of all the orifice shapes investigated.

Compared to the free outflow openings it appears that outflow volume and greatest velocity are influenced by eddy and frictional losses in the nozzle. These results should form an incentive for still further physical studies of the outflow phenomena.

In this respect valuable enlightenment has already been furnished by the highly interesting investigations of Prof. Stodola,*

*See "Zeitschrift d. v. d. Ing.," 1893, No. 1 and following.

according to which the rapid rise of the outflow velocity by the sudden appearance of a drop in pressure at the smallest section of the nozzle is due to the pressure existing in the receiving space.

The measurements of the pressures by Stodola within the nozzle show that the wave formation observed for free discharge also arises within the nozzle. Under circumstances this is continued outside of the nozzle, as shown in the experimental jet in Fig. 19. Here the steam left the nozzle at a pressure of 8 atmospheres.

That the waves visible in the steam jet have their origin within the nozzle, can be seen at nozzle outlet, as the first wave is only partially visible.

# ON PORT AREAS FOR STEAM ENGINES.

By Prof. M. F. Gutermuth, Mechanical Laboratory of the Technical High School, Darmstadt.

Translated from the "Zeitschrift des Vereines Deutscher Ingenieure," March 5, 1904, by William Wachsmann, Associate Member.

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The calculation of steam-port areas as well as the determination of the dimensions of the internal valve mechanisms of steam engines rests essentially on an empirical basis, but which does not offer the designer sufficient reliable data for judging the suitability of his assumptions.

To assume a mean velocity of the steam through the ports of 30 meters per second, about 5,900 feet per minute, is simply a rule of thumb, with which proper valve proportions can only be obtained when special requirements for the most practical sizes of the valve mechanism are not demanded.

Radinger, likewise, in his latest edition of the "Steam engine with high piston speeds," gives merely the following relation, experimentally established, for calculating the width of steam ports:

$$\frac{f}{F} = \frac{1}{30} c_m,$$

in which $f$ equals the port area, $F$ the piston area, $c_m$ the mean piston speed.

Such, and similar, relations are only suitable for an approximate determination of the valve particulars, as these empirical rules are not supported by any actual behavior of the flow of steam through the valve mechanism.

As regards the usual method when calculating and designing a valve gear, it must be made emphatic at the outset that, instead of starting out with the *port area*, the *port opening of a valve*

*mechanism* should form the basis for fixing the proper valve sizes.

The theoretical fundamental law for the opening and closing movement of any valve mechanism is established by assuming that the steam entering or exhausting is equivalent to the momentary volume of the piston displacement; and the resulting velocity of the steam through the valve mechanism remaining constant, being equivalent to a value, deemed permissible, of the head due to velocity and the loss in pressure thereby conditioned.

Hence follows the relation:

$$Fc = fw, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which $F$ equals the piston area, $c$ the momentary piston speed, $f$ the area of the steam port opening, and $w$ the permissible steam inlet or outlet velocity through area $f$.

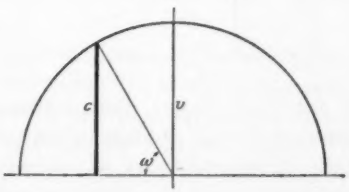
Accordingly, the area of the steam port opening

$$f = \frac{F}{w} c$$

is directly proportional to the piston speed $c$, which bears the following relation to the crank velocity $v$ and turning angle $\omega$ of the crank:

$$c = v \sin. \omega,$$

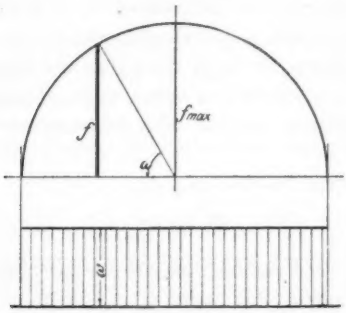
Fig. 1.




consequently the diagram for the piston velocities $c$, Fig. 1, is graphically represented by a circle of radius $v$, equal to the crank velocity described over the piston path; it is also to be regarded as a diagram for the theoretically-required port openings for the

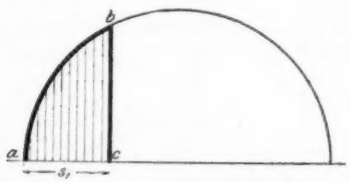
respective piston positions. The velocity diagram is represented by a line parallel to the abscissa axis, Fig. 2.

Fig. 2.




Therefore, to obtain constant entering and exhaust velocities for full stroke the valve mechanism must be moved correspondingly with the ordinates in the semi-circle, *i. e.*, by means of an eccentric set at 90 degrees with the crank, its eccentricity being equal to $f_{max}$ See Fig. 2.

Fig. 3.



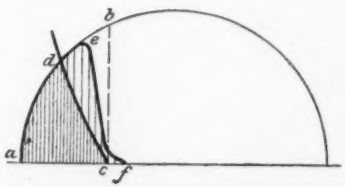

For a shorter cut-off $s_1$, Fig. 3, the port would have to be opened, corresponding to the ordinates $f$, to piston position $c$, and then closed the same instant with an infinitely great velocity.

The latter condition cannot be satisfied in actual practice, as the valve mechanism, while closing the port, can only be moved with finite velocity. Hence, in the graphic representation, the actual closing line varies considerably more or less from the vertical. See Fig. 4.

The nearer the external mechanism of a valve gear conforms to the theoretrical opening and closing laws, the more perfect, from a theoretical point of view, can the gear be regarded; in precision valve gears (trip or drop gears) high-closing velocities are generally obtained by artifical means.

The difference in behavior of the various types of gears is manifest from the closing line; for a slide valve with cut-off it follows the line *cd*, Fig. 4; in trip or controlled-closing gears it follows the line *ef*.

Fig. 4.




Therefore it is the position which the closing line bears to the vertical *bc*, that characterizes the precision gear. The nearer *cd* or *ef* approaches the line *bc* the more perfectly the gear acts as respects satisfying the theoretical law of motion. Consequently the relative course of this closing line to a vertical forms a certain characteristic as to the type of gear and as to the suitability of the gear mechanism chosen.

As the variation of the actual valve motion from the theoretical one is unavoidable, the velocity of the steam also remains no longer constant.

The relation between piston displacement and the quantity of steam admitted and exhausted is still as expressed in formula (1), provided the density and pressure of the steam admitted and exhausted from the cylinder are not varied. To determine the actual steam velocities through the port openings it seems permissible, even though there be slight variations in pressures, again to start out from the formula.

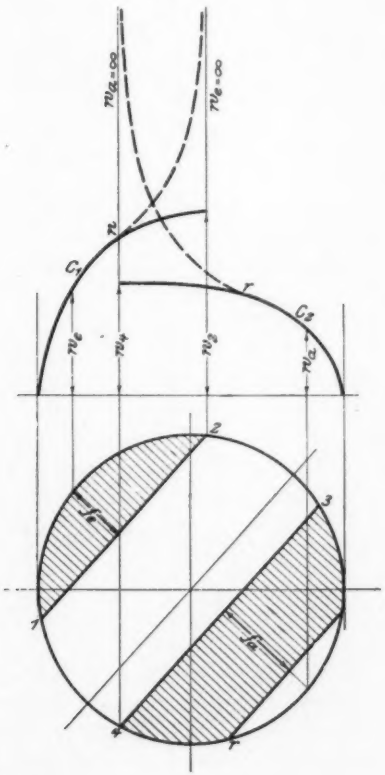
$$Fc = fw,$$

from which

$$w = \frac{F}{f}c.$$

As an example, take a simple slide valve: the variations in velocities for the admission and exhaust periods would be as represented by the two curves $C_1$ and $C_2$ in Fig. 5.

Fig. 5.




In this figure—

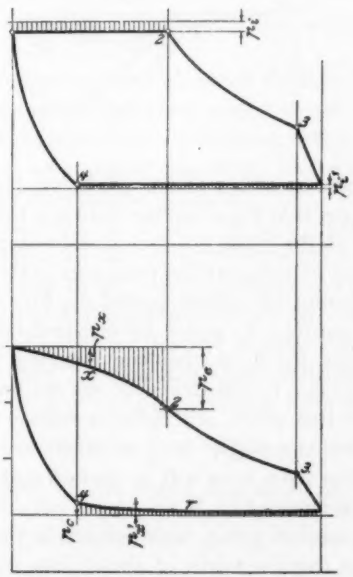
$f_e$ = the port openings during steam admission.
$w_e$ = velocities during steam admission.
$f_a$ = the port openings during exhaust.
$w_a$ = velocities during exhaust.

These curves show that the steam velocities near the end of steam admission and exhaust would have to rise rapidly, and, indeed, become infinite at the moment the valve closes, provided the admission steam fills the cylinder volume under constant pressure or the exhaust steam is expelled through the momentary port opening without change of pressure by the piston.

Imagining that, with increasing steam velocity, there is also a corresponding increase in pressure, this, first of all, explains the phenomena that, during steam admission, there generally occurs a drop in pressure until the beginning of expansion; and near the end of exhaust there is a rise in back pressure until the beginning of compression.

Hence the difference resulting in the course of the steam and exhaust lines of the actual indicator diagram compared to one derived from a perfect gear is shown in Figs. 6 and 7.

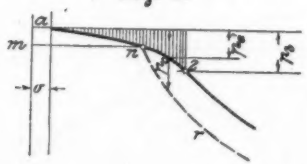
Fig. 6 and 7.



At constant steam velocity, as assumed in the gear action, Fig. 3, the indicator diagram would have to show constant difference in pressure on either side of the ports for the steam and exhaust side, as in Fig. 6, in which $p_i$ represents the head due to velocity for constant steam velocity $w_i$, and $p_i'$, the head due to velocity for constant exhaust velocity $w_i'$. The actual velocities $w_e$ and $w_a$, on the contrary, according to Fig. 5, require increasing heads due to velocity, consequently increasing differences in pressure on either side of the ports, whereby the course of the steam and exhaust lines of the actual indicator diagram are changed, as represented in Fig. 7.

The differences in pressure $p_x$ and $p_x'$ generally designated as losses due to wire-drawing can therefore be deduced from the velocities $w_e$ and $w_a$, Fig. 5, yet only in so far as the pressures arising are requisite for producing these velocities.

Fig. 8.




A closer inspection of the steam admission and exhaust of a cylinder will show that the velocities through the ports are not only dependent on the motion of the valve, but are also influenced by the expansion or compression pressures of the piston motion. For instance, during the steam period $a2$, Fig. 8, on the steam side of piston position $n$, under no circumstances can greater pressures $p_e$ arise for producing the entering velocity of the steam than those due to the steam volume $mn$ under its own expansion. Since live steam still follows from $n$ to 2, the steam line therefore will rise higher than $nr$, about toward $n2$, and the entering velocities from $n$ on will be limited and determined by the pressure differences $p_e'$. If the steam velocities corresponding to these pressures $p_e'$ are incorporated in the diagrams Fig. 5, it will be seen that the curve of actual velocities beginning at

point $n$ varies from curve $C_1$, in the manner indicated. At the moment of cut off the steam velocity $w_e = w_2$ and not $w_e = \infty$, as was calculated from the valve and piston movement.

Similarly it follows for the exhaust side that from a certain point, $r$, the actual exhaust velocities become smaller than those calculated for $C_2$, since the slight rise of the compression causes only a small increase of the pressures required to produce the exhaust velocities.

A strict theoretical investigation on the course of the steam and exhaust lines based on the above referred-to characteristic velocity conditions of the steam and on pressure conditions in a cylinder will shortly be forthcoming by Mr. Blaess. To obtain suitable dimensions for a valve it appears sufficient for all practical purposes to locate that point of the indicator diagram from where an appreciable amount of wire drawing is permissible. This procedure answers the usual requirements that for the greater part of steam admission and exhaust the loss in pressure, and therewith the steam velocities, should not exceed a certain permissible amount.

The velocity curves $C_1$ and $C_2$ which were deduced from the mechanically-connected valve and piston movement can be regarded as valve characteristics in the sense that upon their course is also dependent to a greater extent the course of the steam and exhaust lines of the indicator diagram.

This dependence exists so long as the pressure inside the cylinder under the influence of steam expansion is less than the pressure in the valve chest, being equivalent to the head due to velocity resulting from the steam velocity curve $w$.

* Tests conducted by me for the outflow of steam through rectangular orifices have proven that relatively slight increments in pressure produce proportionate high steam velocities. As an instance, for the ratio $\frac{p}{p_1}$ of the pressures inside and outside of the opening, it was found that when $w = 60$ meters per second (11,810 feet per minute), $\frac{p_2}{p_1} = 0.987$ or $\frac{\Delta p}{p_1} = 0.013$, and

* See preceding article.

when $w = 100$ meters per second (19,680 feet per minute), $\frac{p_2}{p_1} = 0.975$ or $\frac{\Delta p}{p_1} = 0.025$, in which $\Delta p$ represents the difference in pressure between $p_1$ and $p_2$.

Therefore, at a pressure of 10 atmospheres (147 pounds per square inch) absolute and 60 meters per second (11,811 feet per minute) entering velocity, there would be an expected drop of $0.013 \times 10 = 0.13$ atmospheres (1.85 pounds per square inch), and for 100 meters per second a drop of $0.025 \times 10 = 0.25$ atmospheres (3.56 pounds per square inch). These are small pressure losses, producing but moderate loss in energy, even at early cut-offs, and can, without hesitancy, be permitted.

If the same port velocities are assumed for the exhaust steam, then, taking $w = 100$ (19,685 feet per minute) for non-condensing, the back pressure will only amount to $0.025 \times 1 = 0.025$ atmospheres, and when condensing, is reduced to $0.025 \times 0.1 = 0.0025$ atmospheres.

These are pressure losses that seem practically unimportant and are generally not measurable on an indicator diagram.

From these simple figures it is clear that far higher steam velocities can be introduced for calculating the most practical valve dimensions than are permissible according to the usual rule of thumb for determining the sizes of ports.

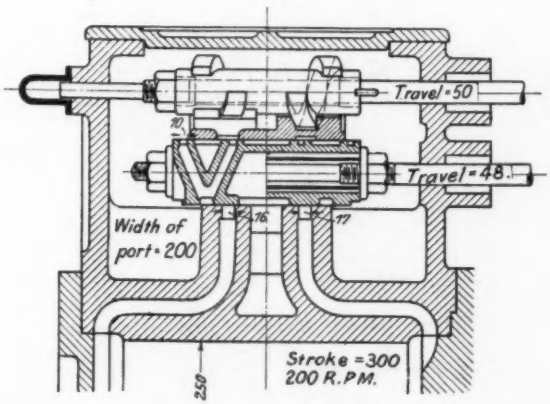
This also refutes the general assumption that the outlet ports should be designed for lower velocities than the inlet ports. On the contrary, the exhaust velocities, in so far as they depend on the piston movement, can be taken much higher, up to 200 meters (39,370 feet per minute) and over, without becoming detrimental.

The correctness of the foregoing statement can be substantiated on any actual gear. As an example, let us take the tests made on the gears of a compound engine and on a 30-horsepower high-speed engine with ordinary slide valve and independent cut-off of the mechanical laboratory at Darmstadt.

The high-pressure cylinder of the compound engine has a controlled poppet valve gear, the low pressure an eccentric driven Corliss gear of the Wheelock type.

Therefore the observations cover the three most important gear types: Common slide valve with long curved passages, Fig. 9 to 12; poppet valves having most unfavorable steam lead, Fig. 13 to 17; and Corliss valves having short ports and simple steam leads, Fig. 18 and 19.

Fig. 9.




In the diagrams of the figures are shown the steam velocities through the port openings of the valves and the thereon dependent actual pressure losses of the entering steam for various degrees of expansion of the different cylinders.

The steam velocities are represented by curves $w$ in the diagrams; those for the poppet valve have been calculated from the lifts, and those for the slide valve from the port openings, according to the former relation $w = \frac{Fc}{f}$.

The corresponding pressure losses were experimentally established by simultaneously taking indicator diagrams from the inside of the cylinder and from the valve chest. The section-lined surfaces represent the losses in pressure respectively.

The diagrams thus obtained for the three different gears without doubt show that the loss in pressure for velocities up to 70

meters (13,779 feet per minute) is unimportant and that even entering velocities of 100 meters (19,685 feet per minute), can be permitted without hesitation. Only by further increasing the entering velocities does wire-drawing become perceptible.

Fig. 10.

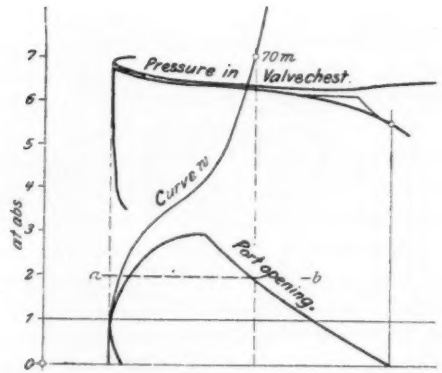



Fig. 11.

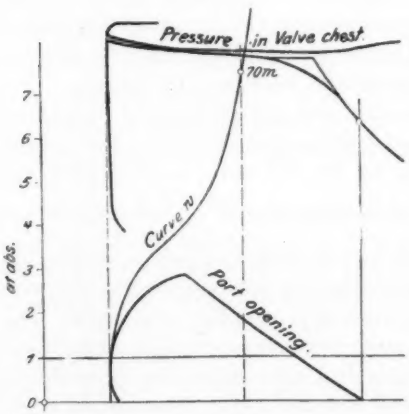


Fig. 12.

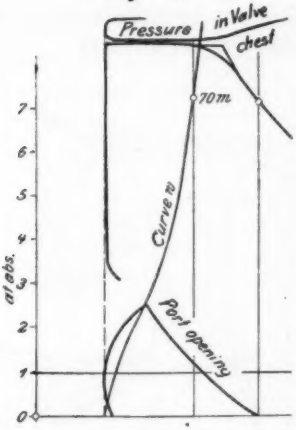
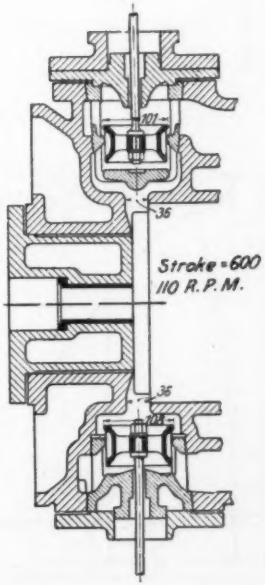

Pressure in Valve chest
70 m.
Curve 70
Port opening
at abs.
0
1
2
3
4
5
6
7

Fig. 13.


101
36
Stroke = 600
110 R.P.M.
35
103

Therefore, for ordinary steam pressures the velocities through the valve mechanism can be taken at 70 to 100 meters per second (13,779 to 19,685 feet per minute).

Fig. 14.

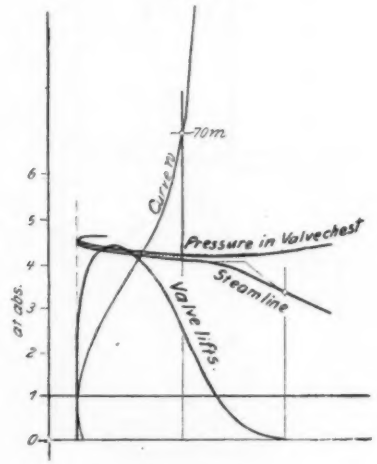



Fig. 15.

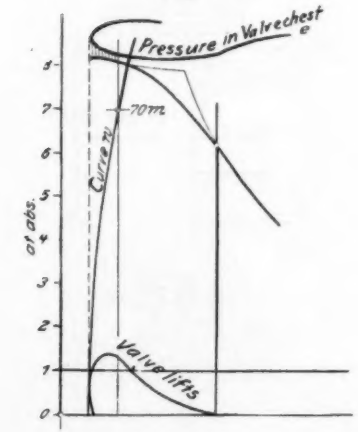


Fig. 16.

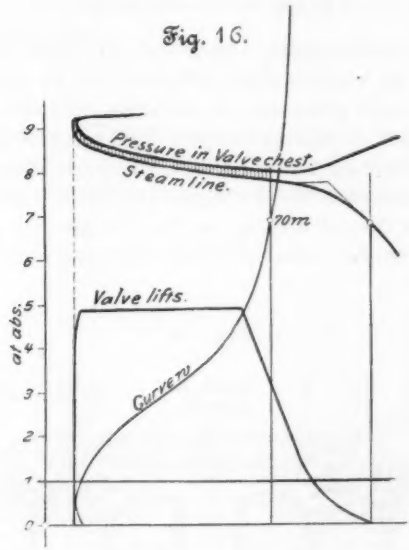
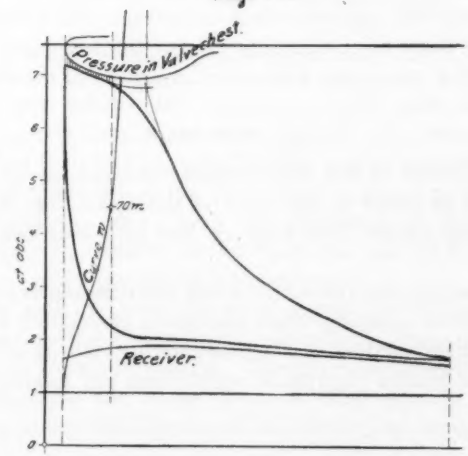

Pressure in Valvechest.
Steamline.
70m.
Valve lifts.
Curve m
at abs.
0
1
2
3
4
5
6
7
8
9

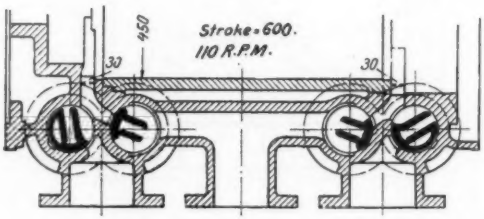
Fig. 17.


Pressure in Valvechest.
70m.
Curve m
Receiver.
at abs.
0
1
2
3
4
5
6
7

### LAYING DOWN NEW GEARS.

To utilize the foregoing theoretical principles of calculation presupposes an entirely different procedure for calculating and determining valve gears than is ordinarily followed. The usual method consists in making the port area, according to empirical ratios, dependent on the piston area, whereupon the rest of the gear is then determined. In regard to this it should be made emphatic that the calculation and the design of a gear, should begin with the *port opening* of the valve and not with the port area.

Fig. 18.




This method of calculation is quite adequate for the steam inlet, while for the exhaust other conditions will in most cases modify the basis of calculation. From the foregoing point of view we shall now make a closer examination of the steam inlet valve.

### STEAM INLET VALVE.

Any criticism of the most suitable proportions of the inlet valve must be based on the form of the steam line desired, its course being limited by a more or less early loss due to wire-drawing.

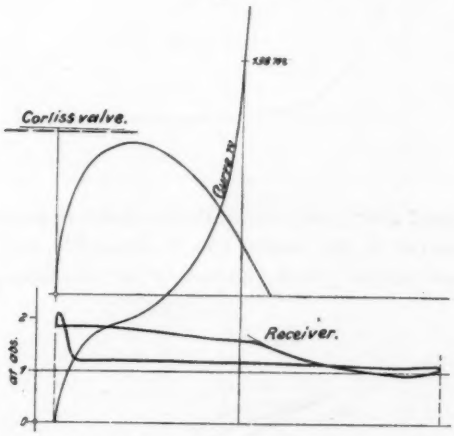
Consequently the form of the steam line determines from which piston position $x$, during steam admission, perceptible wire drawing may be assumed—*i. e.*, where an entering velocity of 70 to 100 meters per second (13,779 to 19,685 feet per minute), may be exceeded.

The area of the port opening $f_x$ for piston position $x$, is calculated as formerly from

$$f_x = \frac{F}{w} c_x.$$

In this formula the piston area $F$ as well as the piston-speed $c_x$ for piston position $x$ are known and for the latter assume the permissible steam velocity $w$ for the inflow area $f_x$.

Fig. 19.




As the gear scheme and the valve diagram give the relative proportions as to sizes of eccentric, laps, etc., the actual working dimension of the valve gear can be determined therefrom as soon as the port openings of the valve for any piston position have been established. Also, with the assistance of the velocity curves, Fig. 5, the course of the steam line relative to the pressure in the valve chest can be followed up.

For one and the same degree of expansion, various cuts-off are obtained during admission according to the losses in pressure permitted, as shown in Fig. 20. Therein $v_{II}$ represents the cut-off calculated for the initial pressure while actually the valve should make possible the cut-off volumes $v_2$, $v_2'$, or $v_2''$ accord-

ing to the course of steam line desired, without causing any appreciable loss of work in the engine with these variations in cuts-off.

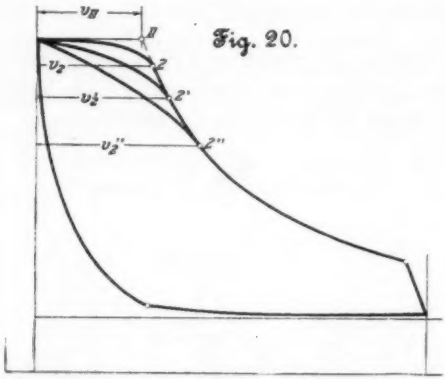
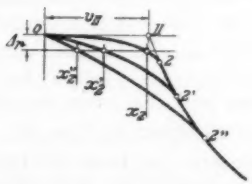



Fig. 20.

If it is found after laying down this probable indicator diagram that the course of the steam line is insuitable, then start out from a more proper piston position $x$ for calculating the port opening.

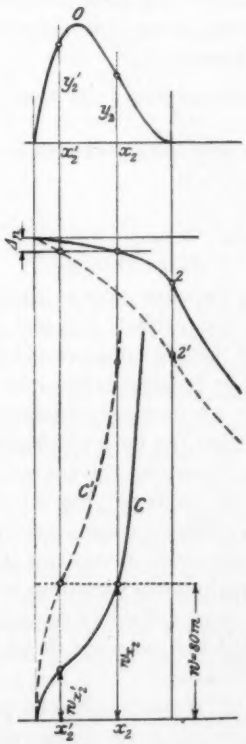
Fig. 21.




For example, let the steam line have the form 02, Fig. 21; then the point $x$ from which $\Delta p$, the head due to velocity, may be exceeded must be moved nearer to the closing point 2, say to $x_2$; whereas if the steam line $02''$ having more drop can be chosen then $x$ must be moved in the opposite direction, say to $x_2''$. In the former case the dimensions and motion of the valve are increased; in the latter they can be reduced to a size suitable for the design.

If the features of design of an inlet valve have been thus far determined, graphically—the law of the opening and closing motion of the valve being known by curve *O*, Fig. 22, and the characteristic by *C*—then the working dimensions for the essential details of the motion of the valve are determined by assuming on curve *C* the piston position where the entering velocity $w$ is equal to 80 meters (15,745 feet per minute), and the corresponding head due to velocity is equivalent to the loss in pressure $\Delta p$.

Fig. 22.



If, for instance, this condition were demanded for the piston position $x_2$, then take the proper ordinate $w_{x2} = w = 80\,(15{,}745)$ from the characteristic $C$ and hence calculate the absolute size of the port area $f_{x2}$ for the governing piston speed $c_2$ at piston position $x_2$, therefore $f_{x2} = \frac{F}{w} c_2$.

Whereas, if permitted to assume an entering velocity of 80 meters (15,745 feet) at piston position $x_2'$, then the steam velocities would be increased during the admision period for the successive piston positions proportional to the ordinates of curve $C$, as shown in curve $C'$.

The head due to velocity and losses due to admission increase correspondingly, and the steam line drops until the end of the cut-off period, about toward $2'$.

The area of the port opening $\frac{F}{x_2'}$ is then calculated from the relation $\frac{F}{w} c_2'$, and the necessary port area for the piston position $x_2$ now becomes

$$f_{x2}'' = f_{x2}' \frac{y_2}{y_2'} = f_{x2} \frac{c_2'}{c_2} \frac{y_2}{y_2'}.$$

therefore, reduced in the same ratio as the piston speed, at $x_2'$ is less than at $x_2$, and the ordinate $y_2$ is less than $y_2'$.

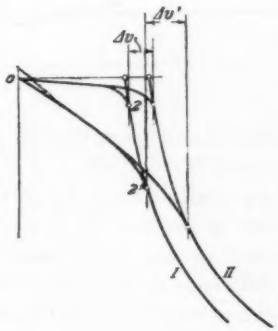
If the steam line $2'$, having considerable drop, is adopted, the valve dimensions can be reduced in the ratio of $f_{x2}'' : f_{x2}$.

In criticising valve proportions obtained in this manner it must be remembered that the form of the steam line determines also the capacity for governing the engine. According to the course of the steam line 02 or $02'$, Fig. 23, there results, for instance, by a variation of the expansion line from I to II, different degrees of variation in the cut-off volumes $\Delta v$ or $\Delta v'$. From this it follows that for nearly equal variations in load, and when the steam line has much drop, considerable more travel will be required for the valve and the governor sleeve than for steam lines with smaller pressure losses.

Hence the form of the steam line has an essential influence on the degree of uniformity for governing as well as on the gear in

general, and should be mainly chosen from this point of view. The loss of work due to wire-drawing will generally be of little consequence, as this loss compared to the work of expansion is, as a rule, small, and, moreover, is again returned in the form of heat during steam admission.

Fig. 23.




EXHAUST VALVE.

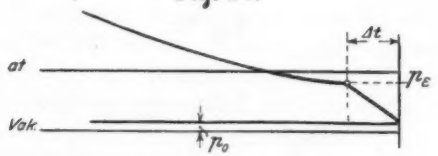
To obtain the maximum work effect, the steam should exhaust at the minimum back pressure. However, to hold the exhaust valve alone responsible for this back pressure is not quite correct. The back pressure is much more influenced by the circumstances of pre-release, the effective opening and length of the exhaust pipes and passages, as well as the change in direction and variation of area of the latter, and the like.

An unfavorable lead of the exhaust pipe to the atmosphere or the condenser may give rise to sensible resistances due to flow, which may amount to several times the resistances due to flow through the valve. This knowledge has led to placing the condenser as close as possible to the cylinder, and to calculating the size of the exhaust discharge according to the permissible resistance due to flow.

As far as the valve gear itself influences the steam exhaust, two vitally different periods must be distinguished: The so-called

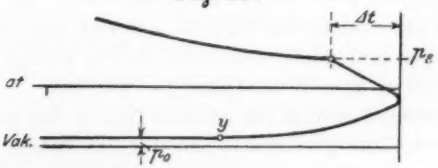
pre-release, during which the steam is exhausted by the pressure at the end of expansion independently of the piston speed; and the actual exhaust period during which the steam is expelled by the piston.

Fig. 24.




The pre-release should be chosen, if possible, so that the exhaust pressure inside the cylinder is attained at the end of the stroke, Fig. 24. This is only possible when the port-opening areas of the exhaust valve, as well as the time elements $\Delta t$ of the pre-release are sufficient to permit an amount of steam to escape, which is equivalent to the difference of the pressures due to the amount remaining at the end of expansion, and that due to the quantity of steam remaining in the cylinder at the end of the stroke. According to this the amount of pre-release will have to be increased or decreased with the pressure at the end of expansion $p_e$ and the number of revolutions of the engines.

Fig. 25.




In the case of extraordinarily high pressures at the end of expansion or high rates of revolution, it might become necessary to let the transition to exhaust pressure be extended to cover a portion of the return stroke, as shown in Fig. 25, so that the piston first begins to exhaust at point $y$. Only during the latter stage of the exhaust period does the resistance due to flow of the

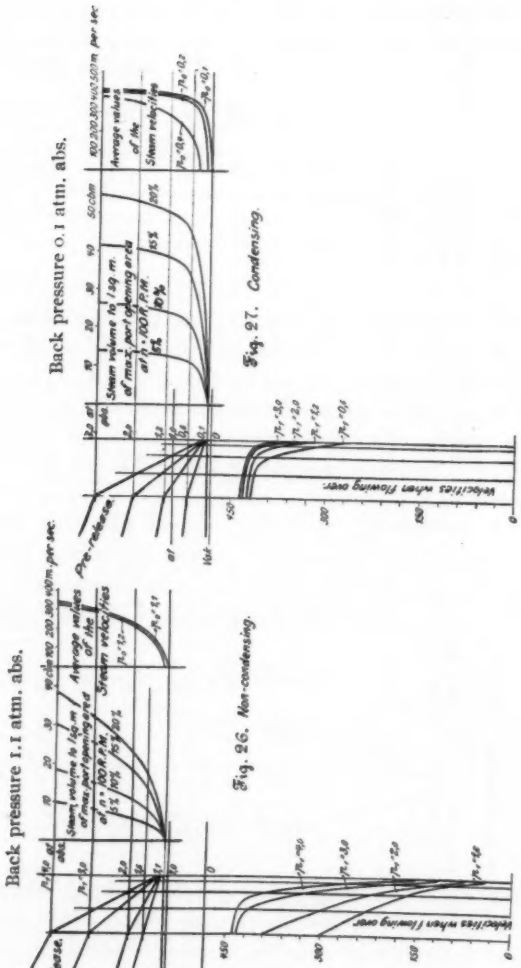
CUBIC METERS OF STEAM FLOWING OVER AT THE END OF PRE-RELEASE, REFERRED TO 1 SQUARE METER OF PORT OPENING AREA.

*For non-condensing, Fig. 26.*

| Pre-release. vH | Back pressure $p_0 = 1.2$ at abs. | | | | Back pressure $p_0 = 1.1$ at abs. | | | |
|---|---|---|---|---|---|---|---|---|
| | $p_1$ | $n = 80$ | 100 | 300 | $p_1$ | $n = 80$ | 100 | 300 |
| 5 | 5.0 | 13.4 | 10.7 | 3.6 | 4.0 | 12.4 | 9.9 | 3.3 |
| | 4.0 | 12.0 | 9.6 | 3.2 | 3.0 | 10.5 | 8.4 | 2.8 |
| | 3.0 | 10.1 | 8.1 | 2.7 | 2.0 | 7.1 | 5.7 | 1.9 |
| | 2.0 | 7.4 | 5.9 | 2.0 | 1.6 | 5.4 | 4.3 | 1.4 |
| 10 | 5.0 | 24.7 | 19.8 | 6.6 | 4.0 | 23.5 | 18.8 | 6.3 |
| | 4.0 | 22.1 | 17.7 | 5.9 | 3.0 | 19.1 | 15.3 | 5.1 |
| | 3.0 | 18.8 | 15.1 | 5.0 | 2.0 | 13.6 | 10.9 | 3.6 |
| | 2.0 | 13.7 | 11.0 | 3.7 | 1.6 | 10.2 | 8.2 | 2.7 |
| 15 | 5.0 | 39.8 | 31.7 | 10.6 | 4.0 | 37.9 | 30.3 | 10.1 |
| | 4.0 | 35.8 | 28.6 | 9.5 | 3.0 | 31.9 | 25.5 | 8.5 |
| | 3.0 | 30.5 | 24.4 | 8.1 | 2.0 | 22.1 | 17.8 | 5.9 |
| | 2.0 | 22.6 | 18.1 | 6.0 | 1.6 | 16.9 | 13.5 | 4.5 |
| 20 | 5.0 | 51.8 | 41.5 | 13.8 | 4.0 | 47.1 | 37.7 | 12.6 |
| | 4.0 | 46.7 | 37.4 | 12.5 | 3.0 | 40.5 | 32.4 | 10.8 |
| | 3.0 | 39.8 | 31.9 | 10.7 | 2.0 | 28.2 | 22.5 | 7.5 |
| | 2.0 | 29.2 | 23.4 | 7.8 | 1.6 | 21.2 | 17.0 | 5.7 |

*For condensing, Fig. 27.*

| Pre-release. vH. | Back pressure $p_0 = 0.4$ at abs. | | | Back pressure $p_0 = 0.2$ at abs. | | | Back pressure $p_0 = 0.1$ at abs. | | |
|---|---|---|---|---|---|---|---|---|---|
| | $p_1$ | $n = 100$ | 300 | $p_1$ | $n = 100$ | 300 | $p_1$ | $n = 100$ | 300 |
| 5 | 3.0 | 12.1 | 4.0 | 3.0 | 13.7 | 4.6 | 3.0 | 13.8 | 4.6 |
| | 2.0 | 10.9 | 3.6 | 2.0 | 13.3 | 4.4 | 2.0 | 13.3 | 4.4 |
| | 1.5 | 8.9 | 3.0 | 1.2 | 12.3 | 4.1 | 1.2 | 12.8 | 4.3 |
| | 1.0 | 7.1 | 2.4 | 0.6 | 11.2 | 3.7 | 0.6 | 11.3 | 3.8 |
| 10 | 3.0 | 23.1 | 7.7 | 3.0 | 25.9 | 8.6 | 3.0 | 26.1 | 8.7 |
| | 2.0 | 21.0 | 7.0 | 2.0 | 25.1 | 8.4 | 2.0 | 25.2 | 8.4 |
| | 1.5 | 17.1 | 5.7 | 1.2 | 23.2 | 7.7 | 1.2 | 24.2 | 8.1 |
| | 1.0 | 13.7 | 4.6 | 0.6 | 21.3 | 7.1 | 0.6 | 21.0 | 7.0 |
| 15 | 3.0 | 36.1 | 12.0 | 3.0 | 41.0 | 13.7 | 3.0 | 41.3 | 13.8 |
| | 2.0 | 33.1 | 11.1 | 2.0 | 39.7 | 13.2 | 2.0 | 39.8 | 13.3 |
| | 1.5 | 27.4 | 9.1 | 1.2 | 36.8 | 12.3 | 1.2 | 38.3 | 12.8 |
| | 1.0 | 22.1 | 7.4 | 0.6 | 33.9 | 11.3 | 0.6 | 34.3 | 11.4 |
| 20 | 3.0 | 47.6 | 15.9 | 3.0 | 53.6 | 17.9 | 3.0 | 54.2 | 18.1 |
| | 2.0 | 43.3 | 14.4 | 2.0 | 51.9 | 17.3 | 2.0 | 52.2 | 17.4 |
| | 1.5 | 35.7 | 11.8 | 1.2 | 48.2 | 16.1 | 1.2 | 50.3 | 16.8 |
| | 1.0 | 28.8 | 9.6 | 0.6 | 44.3 | 14.8 | 0.6 | 44.9 | 15.0 |


Back pressure 1.1 atm. abs.
Pre-release.
Velocities when flowing over.
Fig. 26. Non-condensing.
Back pressure 0.1 atm. abs.
Pre-release.
Velocities when flowing over.
Fig. 27. Condensing.

steam through the valve bear a relation to the piston movement, and the port opening areas are proportional to the amount of back-pressure $p_o$.

As already explained in the foregoing, the actual steam velocities arising during the exhaust period do not at all meet the customary views. Contrary to the usual assumption of 30 meters (5,900 feet) mean steam velocity relative to the mean piston speed, velocities for non-condensing, of 100 meters (19,685 feet) and over, and for condensing 200 meters (39,370 feet) and over, can unhesitatingly be permitted, if only care is taken, when choosing the conditions of pre-release, that the proper amount of exhaust steam can conveniently escape from the cylinder. In condensing engines a further difficulty is yet encountered in that, during the short period of pre-release, the large amount of exhaust steam cannot be condensed rapidly enough, and hence during the return stroke a still further reduction in back pressure often ensues.

If such procedures are to be feared, then to obtain a low constant exhaust pressure a large condenser space is required, and in such cases, quite correctly, cylindrical tanks, the size of large boilers, are used as condensers.

To facilitate the calculations for determining the most favorable point of pre-release of a valve, the table and diagrams, Figs. 26 and 27, have been compiled.

# THE U. S. S. *DENVER.*

## THE SECOND OFFICIAL TRIAL.

By James Nelson Alexander, Associate.

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Owing to failure to reach the contract speed of 17 knots on the official trial of October 22, 1903, the contractors of the protected cruiser *Denver* requested and obtained permission to run a second trial in the hope of at least considerably bettering the 16.4433 knots on first trial, if not to actually obtain the guaranteed speed.

In the report of the trial of October 22, 1903, published in the Journal, February, 1904 (Vol. XVI, No. 1), a full description of the ship and machinery is given, and therefore it will only be necessary here to repeat such few of the principal data as will serve sufficiently to refresh the memory of the reader of this article to enable him to read it without recourse to the first article, except for study of details.

The general dimensions of hull are,

| | |
|---|---|
| Length, L.W.L., feet | 292 |
| Beam, L.W.L., feet | 44 |
| Draught, normal, mean, feet and inches | 15 -9 |
| Displacement corresponding to normal draught (salt water) tons, per inch at L.W.L., tons | 3,196 |
| Wetted surface, square feet | 14,817 |

Of machinery the only data necessary to repeat are,

| | |
|---|---|
| Number of engines | 2 |
| Number of cylinders, each engine | 4 |
| Diameter H.P. cylinder, inches | 18 |
| M.P cylinder, inches | 29 |
| L. P. (2) cylinder, inches | 35½ |
| Stroke, inches | 30 |

PROPELLERS.

| | |
|---|---|
| Number of blades | 3 |
| Diameter, feet | 11 |
| Pitch, feet and inches | 11–11 |
| Helicoidal area, each screw, square feet | 50.26 |
| Projected area, each screw, square feet | 45 |

BOILERS.

| | |
|---|---|
| Number (Babcock and Wilcox type) | 6 |
| Heating surface, square feet | 13,200 |
| Grate surface | 300 |

New propeller blades, of the design shown in the JOURNAL, February, 1904 (Fig. 2, pages 74–5), having been fitted, the *Denver* left the yard of the Neafie and Levy Company February 29, 1904, for a progressive trial at the Delaware Breakwater. On the run down, between Philadelphia and Fort Delaware, considerable damage was done to the copper sheathing by the ice in the channel. On the morning of March 1st, fog obscured the ranges marking the measured course, and it was not until 12.45 P. M. that the fog lifted enough that the ranges could be seen.

It was then arranged to make double runs over the course at 100, 130 and 160 revolutions per minute, and finally two double runs at highest speed attainable. Double runs at 100, 130 and 160 revolutions were successfully made. Two runs over the course were made at about 205 revolutions per minute, but the fog again obscured the ranges and no time interval could be recorded. Fog prevented a continuation of the trial on March 2d and 3d. During the night of March 3d there was a heavy rain and wind storm at the Breakwater. The morning of March 4th brought clear weather, but there was a strong wind and choppy sea, making conditions unfavorable for a trial. It was decided, however, to complete the trial begun on March 1st, and return to Philadelphia. Two double runs and one single run were made. One double and a single run at 211 revolutions per minute, giving a speed of about 16.56 knots per hour, and a horsepower of 5,962.5. The engines ran smoothly, with only moderate vibration and no heating. The mean pitch of propellers, as set on these trials, was 10 feet 6 inches.

Subsequent to the above progressive trials, the contractors requested and obtained permission to shift the propeller blades on their hubs to a coarser pitch. The *Denver* was then placed in dry dock, and the propeller blades were re-set to a pitch of 11 feet 11 inches, and the copper sheathing damaged by the ice on February 29 was renewed. With the increased pitch, the setting of the valve gear was altered to give a later cut-off in the H.P. cylinders.

On March 25 the *Denver* left the builders' yard for a second trial over the Cape Ann course. On the morning of the 26th several runs were made over the measured course at the Breakwater. The maximum number of revolutions made for any run was 187.8, giving a speed of 16.54 knots and a horsepower of 5,773 for the main engines. During these runs the main engines vibrated excessively. To improve this condition the L.P. cut-offs were shortened by notching up the L.P. valve gear 2 inches. This reduced the vibrations considerably, but it was still excessive.

The port H.P. and I.P. crosshead pins heated considerably. They were cooled by use of water and gave no further trouble. It was apparent that the balance of the main engines had to be much improved before the four-hour trial, so after reaching Boston, and previous to the official trial, the cut-offs in the I.P. cylinders were lengthened by reducing the steam lap. This proved to be decidedly effective in reducing vibrations of the engines on the official trial which followed.

### OFFICIAL TRIAL.

The *Denver* left Boston Harbor about 8·30 on the morning of March 31, 1904, for the trial course off Cape Ann. No. 1 stake boat was passed on the run North at 10·55·9½ A. M., and the last stake boat at 12·53·24, making the time interval for the first leg of 33 nautical miles, 1 hour 58 minutes 14½ seconds; 12 minutes and 34½ seconds were consumed in making the turn, and at 1·05·58½, the vessel crossed the line for the run South. At the beginning of the run South, a gasket was blown out on the steam end of the port main feed pump, necessitating the use of one of

the auxiliary feed pumps until the joint could be renewed. The starboard intermediate crosshead pin heated, but it was cooled by use of water. The second leg was completed at 3·04·50½, the time interval being 1 hour 58 minutes 52 seconds.

Ideal weather conditions existed for a speed trial, the sea being smooth and a gentle breeze blowing.

The main engines vibrated considerably at 180 revolutions, but when speeded up to 195 revolutions the vibrations were greatly reduced and the engines ran much more smoothly.

The vibrations of the structural framing of the hull were at all times moderate in degree, and there appeared to be less vibration throughout the after part of the hull than on the first official trial of October 22, 1903.

The main engines and auxiliaries, as a whole, worked very satisfactorily and developed no defects. The air pumps, which are attached to the main engines, made considerable noise, due to abnormal condition of their working.

The feed system worked well and required no attention from the engineering force.

The loss of feed water was only about 1½ per cent. for the four-hour trial.

At the conclusion of the speed trial, the vessel still being under forced draft and the speed the same as during the trial which had just terminated, the steering gear was tested by putting the helm from hard-a-port to hard-a-starboard: the time taken for one man to so operate the helm was 19 seconds.

The friction in the wire-rope transmission from the forward bridge to the valve of the steam-steering engine was appreciably less than during the Boston trial of October 22, 1903, and was considered to be satisfactory.

The steering-gear test having been completed, the vessel was taken to a spot at which the lead gave a sounding of 25 fathoms, and the windlass was tested in the following manner: The vessel being given a slight sternboard, the port anchor was dropped, and when about 60 fathoms had been veered on the port chain the starboard anchor was dropped and both chains veered until the port chain had been paid out to the bitter end and 75 fath-

oms veered on the starboard chain. Began to heave in on both chains at 4·45 P. M. On starting to heave in, the chain was taken in at the rate of 5 or 6 fathoms per minute, but after heaving at this rate a few minutes, the windlass worm began to heat, causing the oil to smoke very badly. At 5·10 P. M. it was necessary to run the windlass extremely slow on account of the heating of the worm, and it was not until 5·20 P. M. that the starboard anchor was brought up to the hawse pipe. At 5·25 P. M. started ahead with the windlass taking in the remainder of the port chain, and at 5·33 P. M. the port anchor was at the hawse pipe.

After completing the windlass test, the watertight doors were operated. The pressure in the accumulator was brought up to 900 pounds per square inch. At 5·48 P. M. the emergency switch was thrown in the pilot house, and 30 seconds afterward the indicators of seven doors showed them to be closed. After 1 minute and 14 seconds all the doors were indicated to be closed.

The two doors located within the coal bunkers abreast the fire rooms, which were covered up with coal and not subject to inspection, were disconnected, and their operation is not included in the test.

It was recommended that in the future no power-operated doors be installed within coal bunkers at points where they are covered on both sides by coal when the vessel has her bunkers filled. Under such circumstances, doors so installed are liable to be opened by the power system, unless special care is taken to disconnect said doors from the system of power operation, and unsatisfactory conditions as to knowing in just what position the doors actually are will inevitably result.

All doors, except the two in the coal bunkers, were then inspected and found to be satisfactorily closed.

The pressure in the accumulator operating the doors, after the doors had been closed by the emergency pressure and then opened at each door, was 720 pounds.

The draught was taken at 7·00 A. M., before the vessel left the inner harbor at Boston for the trial course. The draught was, forward, 15 feet 5½ inches; aft, 16 feet 2½ inches; mean, 15 feet

10 inches. At this time the Trial Board had not arrived. The vessel was at anchor and the small naphtha launch that was subsequently hoisted on board was not yet in position. Correcting for these items, the displacement of the vessel at 8·30 A. M., when starting from Boston Harbor for the trial course was about 3231.3 tons, the weights being as follows:

| | |
|---|---|
| Displacement by draught figures, tons | 3,224 |
| Weight of launch, tons | 2.5 |
| Weight of anchor and chain, tons | 2.8 |
| Weight of Trial Board and guests, tons | 2.0 |
| Displacement when starting for trial, tons | 3,231.3 |

The allowance of 31.3 tons was considered sufficient to carry the vessel from Boston to the middle of her speed trial, so as to insure that the mean displacement during the four-hour speed trial should not be less than 3,200 tons.

PERFORMANCE.

| | |
|---|---|
| Steam pressure at boilers (per gauge), pounds | 268.45 |
| H.P. steam chest, S. engine (per gauge), pds... | 250. |
| P. engine (per gauge), pds... | 243. |
| 1st receiver, S. engine, absolute, pounds | 127. |
| P. engine, absolute, pounds | 127. |
| 2d receiver, S. engine, absolute, pounds | 41. |
| P. engine, absolute, pounds | 40. |
| Vacuum in condensers, in inches of mercury, port | 27.23 |
| starboard | 26.90 |
| Mean effective pressures in cylinders, in pounds per square inch: | |
| Main engines, starboard, H.P. | 101.37 |
| I.P. | 56.13 |
| forward L.P. | 19.38 |
| after L.P. | 21.34 |
| port H. P. | 106.94 |
| I.P. | 55.75 |
| forward L.P. | 20.35 |
| after L.P. | 21.00 |
| Mean pressure, in pounds per square inch on L.P. piston, equivalent to aggregate M.E.P. on all pistons, starboard | 51.878 |
| port | 52.775 |

AUXILIARY MACHINERY.

| | |
|---|---|
| Pump, air, main | Attached. |
| auxiliary | Not used. |
| circulating, H.P. cylinder | 29. |

| | |
|---|---|
| Pump, circulating, L.P. cylinder | 11.625 |
| Dynamo engines, H.P. cylinder | 25.9 |
| L.P. cylinder | 9.687 |

REVOLUTIONS PER MINUTE.

| | |
|---|---|
| Main engines, starboard | 193.8 |
| port | 194.7 |
| Pumps, air, main | Attached. |
| circulating, starboard | 139.3 |
| port, counter | 140.6 |
| main feed, double strokes per minute, starboard | 29.25 |
| port | 29.25 |
| auxiliary, water-service, double strokes per minute | 31.70 |
| Pumps, auxiliary, fire and bilge, double strokes per minute | 31. |
| hotwell, double strokes per minute | 18.40 |
| Blower engines (forced draft), revolutions | 435.7 |
| Speed of ship in knots per hour, corrected | 16.746 |
| Slip of propeller in per cent. of its own speed, based on mean pitch : | |
| Starboard | 27.13 |
| Port | 27.32 |
| Air pressure in ash pit, in inches of water | 1.88 |

INDICATED HORSEPOWER.

| | Starboard. | Port. |
|---|---|---|
| Main engines, H.P. | 741.69 | 798.01 |
| I.P. | 1,082.20 | 1,069.45 |
| F. L.P. | 559.21 | 588.73 |
| A. L.P | 615.80 | 617.90 |
| total | 2,998.90 | 3,074.09 |
| Air pumps, main | | Attached. |
| Circulating pump, main, starboard | | 6.671 |
| port | | 6.671 |
| total | | 13.342 |
| Water-service pumps, total | | 6.492 |
| Fire and bilge pumps, total | | 9.30 |
| Main feed pumps, total | | 48.87 |
| Blower engines for forced draft in fire rooms, total | | 26.424 |
| Ventilating for ship and engine rooms | | Electric. |
| Dynamo engines, one in use during trial | | 23.145 |
| Collective of all main engines | | 6,072.99 |
| main engines, circulating, and feed pumps | | 6,135.20 |
| main and auxiliary engines in operation during trial, | | 6,202.51 |
| all machinery during trial, per square foot of G.S. | | 20 675 |
| H.S. | | .4699 |
| Main engines, circulating, and feed pumps, per sq. foot of G.S. | | 20.451 |
| H.S. | | .4648 |

COAL.

| | |
|---|---|
| Kind and quality | Pocahontas, hand-picked, excellent. |
| Pounds per hour | 14,651 |
| per I.H.P. collective, all machinery in operation | 2.36 |
| per I.H.P. collective, main engines, circulating and feed pumps | 2.23 |
| per square foot of G.S. | 48.86 |
| H.S. | 1.11 |
| Cooling surface, square foot per I.H.P. | .99 |
| Heating surface, square feet per I.H.P. | 2.17 |

From the trial data it will be seen that the horsepower developed was nearly 35 per cent. greater than estimated in the specifications, and yet, generally speaking, the engines and auxiliary machinery operated well and without any injurious results. No doubt this was close to the limit at which such machinery should be run with proper regard for safety and endurance, yet it speaks well for the construction of the parts under such comparatively enormous stresses.

The boilers, especially, deserve more than a passing word of praise, as the 35 per cent. excess over designed output was secured without any priming, with no distress to the boiler elements, and without undue exertion on the part of the personnel. An air pressure of 1.88 inches was maintained and 48.86 pounds of coal was burned per square foot of grate surface per hour.

The important point which these results impress upon the thoughtful sea-going Naval Engineer is that here we have a boiler design which will absolutely insure him the designed output under all ordinary cruising conditions; something which has always been his hope and desire. Heretofore, in Scotch boiler service, the contract boiler power could not be secured and maintained by the force on board, after the ship was in service, except by careful preparatory cleaning and overhauling, a state of preparation which is not a normal condition nor one readily attained on a cruise. No one really expected that naval ships would ever maintain a four-hours' run in commission and develop the horsepower procured on official trial.

The engines, generally, were able to handle the steam, but the boilers' output always fell short. Now, however, with water-tube

OFFICIAL TRIAL, U. S. S.

| No. of run. | Time. | Time interval. | Reading of counter. | Revolutions during interval. | Revolutions per minute. | Steam pressures. In boilers above atmosphere. | Steam pressures. In st'm pipe at engine above atmosphere. | Steam pressures. In H.P. steam chest, absolute. | Steam pressures. In 1st I.P. receiver, absolute. | Steam pressures. In L.P. receiver, absolute. | Vacuum. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *h. m. s.* | *m. s.* | | | | | | | | | **PORT** |
| North run. | 10·55·09½ | ... | 532,820 | ... | ... | ... | 230 | 235 | 117 | 35 | 27·5 |
| | 11·10·09½ | 15 | 535,770 | 2,950 | 196.7 | 254 | 250 | 255 | 125 | 39 | 27·5 |
| | 11·25·09½ | 15 | 538,658 | 2,888 | 193 | ... | 250 | 265 | 132 | 41 | 27·5 |
| | 11·40·09½ | 15 | 541,590 | 2,932 | 194.8 | 276 | 260 | 265 | 125 | 40 | 27·4 |
| | 11·55·09½ | 15 | 544,550 | 2,960 | 197.3 | ... | 255 | 260 | 125 | 45 | 27·5 |
| | 12·10·09½ | 15 | 547,420 | 2,870 | 197.3 | 264 | 251 | 250 | 120 | 38 | 27·2 |
| | 12·25·09½ | 15 | 550,330 | 2,910 | 194 | ... | 248 | 255 | 118 | 38 | 27·2 |
| | 12·40·09½ | 15 | 553,250 | 2,920 | 194.6 | 267 | 252 | 260 | 125 | 39 | 27·2 |
| | 12·53·24 | 13–14½ | 555,828 | 2,578 | 196.1 | ... | 250 | 258 | 120 | 38 | 27·2 |
| South run. | 1·05·58½ | ... | 558,260 | ... | ... | ... | 260 | 265 | 127 | 45 | 27·2 |
| | 1·20·58½ | 15 | 561,125 | 2,865 | 191.0 | 279 | 260 | 257 | 138 | 47 | 27·2 |
| | 1·35·58½ | 15 | 564,175 | 3,050 | 203.3 | ... | 255 | 260 | 137 | 39 | 27·1 |
| | 1·50·58½ | 15 | 567,150 | 2,975 | 198.3 | 281 | 260 | 265 | 133 | 41 | 27·1 |
| | 2·05·58½ | 15 | 570,120 | 2,970 | 198 | ... | 258 | 265 | 137 | 39 | 27·1 |
| | 2·20·58½ | 15 | 572,950 | 2,830 | 188.7 | 267 | 250 | 257 | 130 | 38 | 27·1 |
| | 2·35·58½ | 15 | 575,830 | 2,880 | 192 | ... | 258 | 266 | 127 | 37 | 27 |
| | 2·50·58½ | 15 | 578,728 | 2,898 | 193.2 | 270 | 255 | 265 | 137 | 39 | 27 |
| | 3·04·50½ | 13–52 | 581,325 | 2,597 | 187.3 | ... | 245 | 245 | 105 | 35 | 27·1 |
| Average..... | | ... | ... | ... | 194.7 | ... | 253 | 258 | 127 | 40 | 27·23 |
| | | | | | | | | | | | **STARBOARD** |
| North run. | 10·55·09½ | ... | 522,019 | ... | ... | ... | 237 | 244.7 | 139.7 | 44.7 | 27 |
| | 11·10·09½ | 15 | 524,820 | 2,801 | 186.6 | 254 | 248 | 259.7 | 119.7 | 39.7 | 27 |
| | 11·25.09½ | 15 | 527,753 | 2,933 | 195.5 | ... | 257 | 264.7 | 139.7 | 44.7 | 27 |
| | 11·40·09½ | 15 | 530,687 | 2,934 | 195.5 | 276 | 260 | 269.7 | 129.7 | 41.7 | 27 |
| | 11·55·09½ | 15 | 533,580 | 2,893 | 192.8 | ... | 256 | 264.7 | 129.7 | 40.7 | 26½ |
| | 12·10·09½ | 15 | 536,560 | 2,980 | 198.6 | 264 | 250 | 255.7 | 119.7 | 38.7 | 27 |
| | 12·25·09½ | 15 | 539,426 | 2,866 | 191 | ... | 260 | 265.7 | 132.7 | 42.7 | 27 |
| | 12.40·09½ | 15 | 542,380 | 2,954 | 196.6 | 267 | 255 | 264.7 | 121.7 | 39.7 | 27 |
| | 12·53·24 | 13–14½ | 544,990 | 2,610 | 197.1 | ... | 260 | ... | ... | ... | ... |
| South run. | 1·05·58½ | ... | 547,408 | ... | ... | ... | 260 | 269.7 | 134.7 | 42.7 | 27 |
| | 1·20·58½ | 15 | 550,260 | 2,852 | 190 | 279 | 260 | 269.7 | 123.7 | 40.7 | 27 |
| | 1·35·58½ | 15 | 553,235 | 2,975 | 198.3 | ... | 253 | 261.7 | 119.7 | 39.7 | 27 |
| | 1·50·58½ | 15 | 556,160 | 2,925 | 195 | 281 | 261 | 271.7 | 134.7 | 43.7 | 26½ |
| | 2·05·58½ | 15 | 559,070 | 2,910 | 194 | ... | 260 | 269.7 | 124.7 | 40.7 | 27 |
| | 2·20·58½ | 15 | 561,936 | 2,866 | 191.1 | 267 | 250 | 264.7 | 119.7 | 38.7 | 27 |
| | 2·35·58½ | 15 | 564,790 | 2,854 | 190 | ... | 255 | 269.7 | 119.7 | 39.7 | 26½ |
| | 2·50·58½ | 15 | 567,750 | 2,960 | 197.3 | 270 | 235 | 264.7 | 114.7 | 35.7 | 27 |
| | 3·04·50½ | 13–52 | 570,390 | 2,640 | 190 | ... | 235 | ... | ... | ... | ... |
| Average..... | | ... | ... | ... | 193.8 | 268 | 253 | 265 | 127 | 41 | 26.9 |

* Aft. † Forward. ** Forward auxiliary feed pump used here; main pump stopped for repairs.

*DENVER*, MARCH 31, 1904.

| Position of Link. | Atmosphere. | Temperatures. Engine room. Upper platform. | Engine room. Working platf'm. | Fire room. Above grating. | Fire room. Working level. | Injection. | Discharge. | Hotwell. | Feed. | Base of smoke pipe. (Uptake.) | Revolutions or double strokes per minute. Circulating Pump. | Water-service pump. | Fire and bilge pump. | Feed pump. | Hot-well pump. | Fire-room blowers. | Air pressure in inches of water. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ENGINE** | | | | | | | | | | | | | | | | | |
| | | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Full gear. | | 90 | 80 | 94 | 89 | 56 | 84 | 105 | 126 | 680* | 160 | 12 | 22 | 42 | 22 | 394 | 1.55 |
| | | 82 | 82 | ... | ... | 56 | 88 | 110 | 135 | ... | 140 | 14 | 26 | 34 | 20 | ... | ... |
| | | 82 | 84 | 98 | 92 | 56 | 88 | 106 | 140 | 660* | 136 | 28 | 24 | 22 | 18 | 405 | 1.57 |
| | 52 | 87 | 84 | ... | ... | 56 | 88 | 108 | 130 | ... | 140 | 30 | 28 | 24 | 20 | ... | ... |
| | | 86 | 84 | 99 | 94 | 56 | 86 | 102 | 145 | 650* | 140 | 24 | 30 | 24 | 18 | 392 | 1.47 |
| | | 87 | 85 | ... | ... | 56 | 90 | 100 | 140 | ... | 138 | 22 | 28 | 30 | 18 | ... | ... |
| | | 86 | 85 | 99 | 96 | 56 | 88 | 105 | 148 | 652* | 140 | 30 | 32 | 22 | 18 | 414 | 1.93 |
| | | 86 | 85 | ... | ... | 56 | 86 | 107 | 145 | ... | 140 | 28 | 34 | 28 | 16 | ... | ... |
| | | ... | ... | ... | ... | 56 | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Full gear. | | 88 | 84 | 100 | 90 | 56 | 90 | 102 | 150 | 665* | 136 | 20 | 30 | 22 | 16 | 428 | 1.90 |
| | | 87 | 85 | ... | ... | 56 | 90 | 104 | 145 | ... | 135 | 22 | 32 | 24 | 18 | ... | ... |
| | | 88 | 84 | 100 | 88 | 56 | 88 | 104 | ... | 646* | 144 | 18 | 32 | **36 | 16 | 467 | 2.17 |
| | | 88 | 84 | ... | ... | 56 | 86 | 102 | ... | ... | 140 | 20 | 34 | ... | 18 | ... | ... |
| | | 88 | 84 | 100 | 84 | 56 | 86 | 105 | ... | 645* | 145 | 20 | 32 | **34 | 16 | 484 | 2.23 |
| | | 88 | 84 | ... | ... | 56 | 88 | 100 | ... | ... | 144 | 22 | 34 | ... | 16 | ... | ... |
| | | 88 | 84 | 100 | 80 | 56 | 90 | 102 | 160 | 644* | 135 | 22 | 32 | **33 | 16 | 499 | 2.25 |
| | | 88 | 84 | ... | ... | 56 | 90 | 103 | 162 | ... | 138 | 24 | 34 | ... | 18 | ... | ... |
| | | ... | ... | ... | ... | 56 | 88 | 104.1 | 143.8 | 656* | 140.6 | 22.3 | 30.3 | 27.2 | 18 | 435 | 1.88 |
| **ENGINE** | | | | | | | | | | | | | | | | | |
| | | 90 | 80 | ... | ... | 56 | 86 | 108 | 130 | ... | 145 | 30 | 24 | 38 | 20 | ... | ... |
| Full gear. | | 82 | 82 | 94 | 89 | 56 | 88 | 112 | 145 | 680† | 138 | 46 | 28 | 38 | 18 | 394 | 1.55 |
| | | 82 | 84 | ... | ... | 56 | 86 | 112 | 146 | ... | 144 | 44 | 28 | 36 | 20 | ... | ... |
| | | 87 | 84 | 98 | 92 | 56 | 88 | 115 | 150 | 660† | 136 | 42 | 30 | 32 | 22 | 405 | 1.57 |
| | 52 | 86 | 84 | ... | ... | 56 | 88 | 108 | 150 | ... | 134 | 32 | 32 | 36 | 20 | ... | ... |
| | | 87 | 84 | 99 | 94 | 56 | 88 | 110 | 155 | 650† | 140 | 30 | 30 | 30 | 18 | 392 | 1.47 |
| | | 86 | 85 | ... | ... | 56 | 90 | 110 | 155 | ... | 135 | 30 | 30 | 26 | 18 | ... | ... |
| | | 86 | 85 | 99 | 96 | 56 | 88 | 112 | 150 | 652† | 138 | 32 | 28 | 28 | 20 | 414 | 1.93 |
| | | 88 | 85 | ... | ... | 56 | 92 | 105 | 160 | ... | 144 | 36 | 32 | 36 | 20 | ... | ... |
| | | 87 | 84 | ... | ... | 56 | 92 | 108 | 155 | ... | 140 | 34 | 34 | 34 | 18 | ... | ... |
| Full gear. | | 88 | 85 | 100 | 90 | 56 | 90 | 108 | 165 | 665† | 144 | 32 | 34 | 30 | 20 | 428 | 1.90 |
| | | 88 | 84 | ... | ... | 56 | 88 | 110 | 167 | ... | 145 | 30 | 36 | 28 | 18 | ... | ... |
| | | 88 | 84 | 100 | 88 | 56 | 88 | 112 | 168 | 646† | 140 | 22 | 34 | 28 | 18 | 467 | 2.17 |
| | | 88 | 84 | ... | ... | 56 | 88 | 114 | 165 | ... | 142 | 24 | 36 | 28 | 20 | ... | ... |
| | 52 | 88 | 84 | 100 | 84 | 56 | 90 | 108 | 166 | 645† | 135 | 32 | 36 | 30 | 18 | 484 | 2.23 |
| | | 88 | 84 | ... | ... | 56 | 90 | 112 | 165 | ... | 136 | 30 | 38 | 30 | 18 | ... | ... |
| | | 88 | 84 | 100 | 80 | 56 | 90 | 112 | 170 | 644† | 134 | 32 | 36 | 28 | 20 | 499 | 2.25 |
| | | 88 | 84 | ... | ... | 56 | 90 | 110 | 172 | ... | 137 | 34 | 34 | 28 | 20 | ... | ... |
| | | ... | ... | ... | ... | 56 | 89 | 110.4 | 157.3 | 656† | 139.3 | 33 | 32.2 | 31.3 | 19 | 435 | 1.88 |

Coal used on trial, 61,000 pounds. Coal per hour, 14,659 pounds.
Kind of coal, Pocahontas, hand picked.

boilers, properly designed, the whole status of cruising vessels is changed and they are placed upon a plane of reliability regarding their motive power never before reached.

It is most obvious that the designed output of a Naval boiler should not be the highest to which it can be safely forced when new, but should rather be that which, under ordinary cruising

DETAILS OF VALVE SETTINGS.

| | H.P. | | I.P. | | L.P. | |
|---|---|---|---|---|---|---|
| Travel of valve, inches | 5 | | 5 | | 5 | |
| Side of valve on which steam is taken | Inside. | | Outside. | | Outside. | |
| | Top. | Bot. | Top. | Bot. | Top. | Bot. |
| Width of port, inches | 1½ | 1½ | 1½ | 1½ | 1½×37 | 1½×37 |
| Steam lap, inches | 1 5/32 | 1 | 1 1/16 | 1 7/32 | 1 5/64 | 1 |
| Exhaust lap, inches | −5/16 | 0 | −3/32 | +3/32 | +3/32 | +7/16 |
| Angular advance, degrees | 27¼ | | 39½ | | 56½ | |
| Steam lead, angular, degrees | 1.75 | 4 | 17.5 | 20 | 30.25 | 32.75 |
| linear, inches | 3/64 | 1/16 | 3/32 | 1 1/16 | 9/64 | 1 3/32 |
| Cut-off, in inches | 25.14 | 23.34 | 23.33 | 20.88 | 19.36 | 15.66 |
| decimal of stroke | .838 | .778 | .777 | .696 | .645 | .522 |
| Exhaust release, in inches. | 27.9 | 27.9 | 26.7 | 26.55 | 24.9 | 24.51 |
| Compression, in inches | 1.125 | 1.35 | 3.45 | 3.3 | 8.34 | 7.5 |
| decimal of stroke | .0375 | .045 | .115 | .11 | .278 | .25 |
| Steam opening, inches | 1 1/16 | 1¼ | 1 1/16 | 1 1/32 | 1 9/32 | 1¼ |
| Exhaust opening | Full port. | | Full port. | | Full port. | |

CYLINDER CLEARANCES TAKEN FROM WORK.

| Cylinders. | Vol. clearances. | Vol. clearances. | Lineal clearances. |
|---|---|---|---|
| | *cu. in.* | *per ct.* | *inches.* |
| High pressure, starboard engine, top | 1,415 | 18.5 | 9/32 |
| bottom | 1,617 | 21.1 | 29/64 |
| port engine, top | 1,473 | 19.3 | 1/4 |
| bottom | 1,502 | 19.6 | 7/16 |
| Intermediate pressure, starboard engine, top | 2,455 | 12.3 | 9/32 |
| bottom | 2,945 | 14.8 | 21/64 |
| port engine, top | 2,402 | 12.1 | 1/4 |
| bottom | 2,801 | 14.1 | 17/64 |
| Forward low pressure, starboard engine, top | 3,148 | 10.6 | 13/64 |
| bottom | 3,696 | 12.4 | 7/16 |
| port engine, top | 3,119 | 10.5 | 1/4 |
| bottom | 3,783 | 12.7 | 7/16 |
| Aft low pressure, starboard engine, top | 3,148 | 10.6 | 1/4 |
| bottom | 3,754 | 12.6 | 7/16 |
| port engine, top | 3,350 | 11.2 | 9/32 |
| bottom | 3,696 | 12.4 | 7/16 |

conditions, can be secured at any day or hour on any voyage, and it is most gratifying that this is now secured to our ships without excessive weight. But even weight considerations should not blind the Navy Department to the paramount advantages of reliability of output.

MACHINERY WEIGHTS.

| Group. | | Tons. |
|---|---|---|
| I. | Main engine cylinders, receiver pipes, etc., | 28.027 |
| II. | Shafting, | 20.910 |
| III. | Main engine framing, bed plates and shaft bearings, | 25.058 |
| IV. | Main engine reciprocating parts, | 7.604 |
| V. | Main engine valve gear, | 7.489 |
| VI. | Main condensers, | 12.302 |
| VII. | Main air and circulating pumps and engines, | 5.262 |
| VIII. | Propellers, | 8.146 |
| IX. | Main boilers and casings, | 95.756 |
| X. | Boiler fittings, | 38.474 |
| XI. | Smoke pipes and uptakes, | 26.590 |
| XII. | Steam and exhaust pipes and valves, | 15.114 |
| XIII. | Suction and discharge pipes and valves, | 18.204 |
| XIV. | Lagging and clothing, | 4.414 |
| XV. | Floors, gratings, etc., | 14.441 |
| XVI. | Auxiliaries, | 20.902 |
| XVII. | Feed heaters, oil and water service, separators, instruments, gear, tanks, etc., | 16.217 |
| XVIII. | Water, | 37.492 |
| XIX. | Tools and spare parts, | 17.540 |
| XX. | Distilling, heating and refrigerating plants, | 21.314 |
| XXI. | Pipes and valves to dynamo, steering and windlass engines, | 3.847 |
| | Total, | 447.367 |

POST-TRIAL EXAMINATION.

The post-trial examination of the machinery, boilers and appurtenances of the *Denver* was made by the Machinery Trial Board, April 7, at the works of the contractors. The Board made the following report:

MACHINERY.

1. *Cylinders.*—All the cylinders were found in good condition.

2. *Pistons.*—All the pistons and their rings were found in excellent condition, there being no evidence of cutting or undue wear.

3. *Cylinder Liners.*—Since the previous trial a new liner was fitted in starboard high-pressure cylinder to allow piston to override liner at each end.

4. *Valves and Valve Chests.*—All valves, rings and chests were found in excellent condition.

5. *Pumps.*—All pumps and their valves were found in good condition. The plunger packing was found in good condition and tight. In order to facilitate overhauling discharge valves of air pumps, it is recommended that hole plates be fitted in air chamber.

6. *Journal and Bearings.*—The crank pins and main thrust bearings were found in good condition. The starboard intermediate crosshead pin and brasses were scored. It is recommended that all crosshead pins be smoothed up and the brasses scraped where necessary.

7. The main and auxiliary condensers were filled with fresh water and the tubes found tight. A tube was drawn from the port main condenser; there was an absence of grease and the tinning of the tube found in good condition. With present location of auxiliary condenser, it will be difficult to renew the tubes, it being necessary to remove the outboard waterhead and tube sheet to make such renewal. To protect the tubes in main condensers from the severe action of the jet from H.P. drains, it is recommended that baffle plates be fitted.

BOILERS.

8. *Steam Drums.*—The interior of steam drums was found clean and in excellent condition.

9. *Tubes.*—The tubes were found in excellent condition, with no indication of warping. The appearance of the water side of tubes shows that muddy water had been used in the boilers. All tubes should be cleaned and washed out. In order to protect

the ends of the tubes expanded into the drums, it is recommended that all the composition pipes and fittings within these drums, not tinned, should be removed and tinned.

10. *Casings.*—The casings were found in excellent condition. There was no evidence of warping.

11. *Linings.*—The brick work within the casings was found in excellent condition.

12. *Grate Bars.*—The grate bars were found generally in fair condition. It is recommended that bars be removed, cleaned and renewed where necessary.

13. *Appendages and Fittings.*—All appendages and fittings of boilers were found in good condition with the exception of a leaky joint between drum and auxiliary feed check of boiler B, and nozzles of extinguishers in back ends of furnaces of all boilers. It is recommended that these be renewed and new gasket fitted in leaky joint.

AUXILIARY MACHINERY.

14. *Evaporators.*—Special attention is called to the unsuitable location of evaporators. The arrangement is such that it not only entails unusual hardship on the men operating them, but in the matter of scaling and repairing, it will be difficult to keep them in an efficient condition, especially when steaming. In addition, as located, it will require the removal of steam pipes, gratings, hand rails, etc., to allow the withdrawal of coils for scaling which usually is found necessary monthly. It is recommended that the location be changed to the deck forward adjacent to the workshop, or to the spar deck between the smoke pipes.

15. *Distillers.*—In view of the frequent priming of and carrying over salt water from evaporators when used on auxiliary exhaust for make-up feed for boilers, we recommend distillers of sufficient capacity to distil all water for make-up feed and for ship's use.

16. *Fresh-Water System.*—We recommend the installation of a small steam pump to supply fresh water to the various tanks in the gravity system.

17. *Drainage.*—We recommend that the bilge pumps in the fire rooms be connected to the auxiliary drain.

18. *Air Locks.*—As the air lock between the fire rooms is not necessary, it is recommended that it be removed. This will allow ready access to the backs of the two after boilers; and that the flooring in passageway between air lock and engine rooms be made portable, in order to permit access to pipe joints for repairs.

19. *Store Rooms.*—It was noticed that the engineer's store rooms are only partly fitted with shelving. We recommend that proper shelving and bins be fitted for storage of usual stores and supplies.

20. *Whistle and Siren.*—The tones emitted from the whistle and siren are not of sufficient depth and strength. We recommend that larger whistle and siren be fitted when the vessel is turned over to the Government.

GENERAL OBSERVATIONS.

21. The installation of the machinery in the engine rooms is so crowded that the work of overhauling and repairing is made very difficult.

22. It was observed that the engine and boiler spaces were insufficiently lighted, and we recommend that seventeen (17) additional electric lights be installed in engineering department.

# NOTES.

## MARINE STEAM TURBINES.

The progress towards popularity of the marine steam turbine is gratifying, but it is generally realized that the one important question yet to be determined is that of relative economy as compared with the existing triple-expansion reciprocating engine; while some doubt may yet exist as to the reliability of the thousand curved segments which form the blades mounted on the shaft and on the fixed casing, and which enable the steam to give rotary motion to the shaft. Time alone can decide the latter point, but it is encouraging to know that examinations of turbines which have been running for some years show practically no change on the surface. Although the turbine has been in use now for many years driving dynamos, the application for marine purposes dates only from 1897—in the *Turbinia*, a more or less experimental craft. The first practical application in a commercial ship was in the *King Edward* in 1901. The success of this steamer resulted in a second vessel being ordered.

These vessels gave satisfactory results; but naval architects, generally, were not quite convinced that the turbine-driven propeller was sufficiently large in diameter or had sufficient area to give efficiency in a heavy seaway. It is well known that as turbines require to be driven at a very high speed of rotation, the propellers used with them are limited in both diameter and area. The diameter of propellers in such vessels as are now in service is only about one-half that of screws driven by reciprocating engines of equal power, the blade surface being only about one-fourth. Parsons and Denny, however, entertained no doubt—probably from experience—of the behavior of the ships in seas met with in the Firth of Clyde, and they guaranteed satisfactory results in Channel service, whereupon the Southeastern and Chatham Railway Company and the London, Brighton and South

Coast Railway Company decided to adopt the system in their respective Channel services between Dover and Calais and between Newhaven and Dieppe. This decision was of high importance, in respect that it enabled a demonstration to be made last year of the efficiency in the very heavy seas which are experienced in the English Channel.

When Biles, Gray and Co. were consulted by the Midland Railway Company regarding the construction of four vessels for the new Heysham and Irish service, we understand they investigated this question, and, as a result, the directors of the company determined to take the cautious course of constructing two of the vessels on the turbine system and two with reciprocating engines. As all four vessels are alike in their design, differing only in the type of propelling machinery adopted, a unique opportunity is offered for thoroughly testing the comparative economy of the two systems. It is true that the Admiralty, who have closely watched the progress of the turbine, have sought for opportunities for comparative trials in naval vessels, Sir W. G. Armstrong, Whitworth and Company having consistently advocated the application of the system to warships; but up till now a series of misfortunes has prevented the carrying out of complete trials in warships. It will, however, be possible at an early date to compare the performance of two torpedo-boat destroyers and two third-class cruisers, the only varying condition in each class of ship being the propelling machinery. But it is scarcely necessary to again enforce the point that Navy ships differ materially from merchant ships. In the one case the full speed is almost the exception, 90 per cent. of the steaming being done at low powers, whereas the merchantman is always running at full speed. Because of this, the designs of turbines for war and merchant ships necessarily differ, and, moreover, there is doubt as to whether a high efficiency can be realized at low powers. Shipowners, therefore, regard with keen interest and expectancy the results of the performances of these Midland vessels, and hope that the Midland Railway Company, with their characteristic progressive policy, will do what they can to assist towards the solution of the very important problem now occupying so much attention.

What is wanted is that two of those ships, say the *Londonderry*, fitted with turbine machinery, launched by Denny, and the *Antrim*, tried with successful results by John Brown and Co., or the *Donegal*, launched by Caird and Co., should be sent to sea together so as to eliminate weather and sea conditions, and that a series of exhaustive trials at various speeds should be conducted, and careful data collated to show the consumption of water and also the consumption of coal of equal calorific value in each ship. Such a series of trials would at once overcome the difficulties hitherto experienced of eliminating many variants, and would afford data which would be both reliable and precise. Engineers would readily accept such evidence of the efficiency, or otherwise, of the turbine, because such trials would be under the directions of Professor Biles and his partner, Mr. Gray, who have had such long experience with experimental research and the design of channel steamers.

In the *Antrim* and *Donegal* the engines and boilers are exactly the same; and with a view to arriving at the best possible results with reciprocating engines, slightly different propellers are being tried, so that the better vessel of the two may be looked upon as representing the best that can be done with reciprocating machinery. In the *Londonderry* the boilers are exactly the same as in the two vessels named, but the steam pressure has been reduced because of the belief that with a turbine there is nothing like the same gain due to higher pressures as with reciprocating engines. This reduction of pressures, and its consequent reduction of weight, may be considered as an attribute of the turbine. The size of turbine has been fixed so as to give about the same power, and therefore equal speed, as in the ships with reciprocating engines. In a comparison between the results of the *Londonderry* and those got with the reciprocating-engine ships we shall see all the advantages inherent to a turbine. This advantage largely shows itself in reduced displacement—about 200 tons; but as it is anticipated by the builders of the *Londonderry* that they will attain a higher speed, there may be a still greater advantage. In the *Manxman*, the fourth vessel of this class, shortly to be launched from Vickers' works at Barrow-in-Fur-

ness, the boilers are exactly the same as in the *Antrim* and *Donegal*, but the steam pressure is 200 pounds, as compared with 150 pounds in the *Londonderry*, and the size of the turbines has been fixed so as to give the maximum power for which the boilers can supply steam. This, of course, involves a greater weight of turbine machinery than in the *Londonderry*, but the total is still less than that of the reciprocating engines in the other vessels. We have thus two cases for comparison of turbine machinery—one with fixed conditions as to speed and power, to give a measure of the advantage of the turbine over reciprocating machinery; another in which the speed and weight of machinery are practically unlimited; and we shall see what extra speed this system can maintain. This scheme puts the experiment on a scientific basis, and the ships, while satisfactory to the Midland Railway Company, will produce data of the highest value to engineering science and to the development of the turbine.

The extremely fine lines of the ships approach the Admiralty coefficient of 0.5, now adopted in many of our finest cruisers, so that the propulsive efficiency should be satisfactory. The vessels are 330 feet long, have a beam of 42 feet, and a depth, molded, to upper deck of 18 feet. Carrying a cargo of 300 tons deadweight, and with the full complement of 180 first-class and 80 third-class passengers, the displacement will be 2,600 tons at a draught of 13 feet 6 inches in the case of the vessels driven by reciprocating engines, and 2,400 tons at a draught of 6 inches less for the turbine-driven steamer *Londonderry*. This reduction in weight is practically all due to the adoption of the turbine machinery. The steam-generating system in all the ships is alike. There are two double-ended boilers and one single-ended boiler. The reciprocating engines for the *Antrim* and the *Donegal* are of the four-cylinder triple-expansion type, the power being uniformly distributed throughout the four cylinders; while in the turbine system there are three turbines, one high-pressure mounted on the center shaft and two low on the side shafts. The reversing turbine is usually fitted in the same casing abaft the low-pressure turbine on the side shafts,

these working, of course, in vacuum while the ship is going ahead.

Deferring the detail description we may deal here with the interesting question of weights. One large item in the economy of weight is in the shafting. The diameter of the propeller-shaft in the reciprocating engines is 12 inches, as against 8 inches in the turbine ship; the weight of the latter is only 45 per cent. of the former. The propellers differ in diameter very materially, as it is anticipated that the reciprocating engines will run at 180 revolutions, whereas the turbine propellers will make 500 revolutions in the case of the side propellers, and 600 in the case of the center propeller. The *Donegal's* propellers have a diameter of 11 feet, there being three blades; while the *Londonderry's* propellers are four-bladed, and have a diameter of 5 feet 6 inches. The ratio of pitch to diameter is less in the turbine boat than in the others. It is obvious that with an increase of revolutions for the same speed there would be a corresponding reduction of pitch. If the ratio of pitch to diameter be constant, the number of revolutions is inversely proportional to the diameter. It has been found by experience that when so great a reduction as this is made the diameter of the propellers becomes too small for efficiency, and to obtain increased efficiency the diameter is increased. This involves a greater peripheral speed, and consequent loss due to the friction of the blades; but, again, for other reasons, increased speed more than counterbalances this. In fact, at the present time, the turbine itself has passed beyond the experimental stage, while the problem of the propeller connected with the turbine is still not finally settled.

In connection with the propellers of the reciprocating engines, it may be stated that the first of these vessels, the *Antrim*, had a preliminary trial last week, and obtained the expected speed with less than the indicated horsepower provided. It may also be stated here that the *Princess Maud*, built by Denny for the Larne and Stranraer route, and the fifth turbine vessel built by the firm, who have six others on hand, exceeded by 2 miles per hour the guaranteed speed of 20 knots. In the more recent vessels, the initial trouble of small diameters of propellers seems

to have been overcome, for whereas in the *Turbinia*, the *Cobra*, the *Viper* and the *King Edward*, more than one propeller was placed on each shaft, we now have a reversion to the ordinary practice of a single propeller. This simplifies the stern structure and brings the turbine ship more into line with ordinary practice. The differences in hull structure involved are thus gradually being eliminated, although the multiple shafts involve cutting away of the dead wood and the adoption of a balanced rudder. These features, however, are not peculiar to turbines, but have been adopted in vessels having reciprocating engines.

It has been very clearly demonstrated by Parsons, in his contributions to the various societies, that one of the most important elements of efficiency in the turbine is that of terminal steam pressures. Everything that can be done to reduce this adds to the efficiency of the turbine, while a corresponding addition to the initial pressure produces a comparatively small effect. Consequently, the boiler pressure of vessels fitted with turbines has been kept comparatively low—from 150 pounds to 170 pounds—while every effort is being made to reduce the back pressure by increasing the vacuum. In the reciprocating engines, the air-pumps are usually driven off the main engines. In the turbine vessels, this has never been the case; the air-pumps are driven independently, sometimes in conjunction with circulating pumps and sometimes completely alone. In one of the Midland turbine boats—the *Manxman*—building at Vickers' works, this latter arrangement is followed, with the addition of a vacuum augmenter, to which we shall refer in dealing with the trials of the vessel. In the case of the other turbine ship, Weir is fitting a combination equipment, consisting of their independent air-pumps, supplemented by dry-air pumps worked in conjunction with the circulating-pump engines. In the two ships with reciprocating engines, again, Weir's independent beam air-engines are used, as these represent the tendency, becoming more pronounced in recent designs, of freeing the main engines from all auxiliary complications. The results of the trials of these pump installations will be looked forward to with great interest, as the

relative advantages will be determined in the forthcoming steam trials of these vessels.

It may be thought that there are some disadvantages in the turbine which will outweigh its advantages; but it is difficult to find them. The space occupied is the same, the weight is lower in the ship, so that while the weight of machinery is less, other weights may be placed higher. The facility for overhaul is certainly as great in the turbine machinery as in the other type, and any one who has seen a turbine-engine room will admit that it lacks the crowded appearance of a reciprocating-engine room. The propellers being smaller, therefore project less beyond the line of the ship, and are less liable to damage. It is difficult to say how the center propeller could possibly be injured. In the later installations, the go-astern turbines have been steadily increased in power: in the *King Edward* this power was comparatively small; in the *Queen* it amounted to one-half of the full go-ahead power of the engines; in the *Londonderry* and *Manxman* it will be a still higher proportion—about 60 per cent.

The cost of manufacture can hardly be compared with that of reciprocating machinery, as the turbine production is in its infancy. All the years of effort which have been put into cheapening the cost of reciprocating engines have yet to come to the turbine. Yet even with this disadvantage the turbine is not appreciably more costly than the reciprocating engine. In the case of the *Londonderry*, which affords a direct comparison for speed with the other ships, the additional cost is less than 2 per cent. of the total cost of the vessel. Undoubtedly, as the manufacture becomes more systematized the difference will be on the other side of the ledger. As to cost of upkeep of turbines, experience is practically nil; but there is no evidence to show that there is anything to fear on this account. The cost of running, so far as attendance is concerned, is undoubtedly less, there being in existing vessels at least two men less in the engine room than in the case of ships with reciprocating engines of equal power and speed. With respect to coal consumption, which is the important thing in the cost of running machinery, the trials of the new boats will afford complete information; and

we hope that the comparative results, not only on trial, but on service, for which arrangements are being made, will be placed at our disposal in the near future.

To illustrate the growth of the turbine, we may remark further that the electric light and power plant of the *Londonderry* is being driven by small Parsons turbines, while in the case of the *Manxman* it is being operated by De Laval turbines; and the electric current, in addition to running the lights, will operate steering apparatus in duplicate of the ordinary steering gear. The De Laval turbine seems, at least, to be as suitable for the the small power installation as the Parsons, and the comparative results of these two turbines will be looked forward to with interest. In short, these comparatively small Channel steamers seem to be of an unusually interesting type, and, in addition, to have possibilities of education which many of the larger vessels do not possess.—"Engineering"—May 6.

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REPORT OF THE CUNARD TURBINE COMMISSION.

The Cunard Turbine Commission was appointed last September to consider the advisability of adopting turbine machinery in the new fast steamers which the Cunard company are to build under their agreement with the Government, and their report is confidential to the directors of the company. The committee consisted of Mr. J. Bain, the general superintendent and superintending engineer of the Cunard company (chairman); Sir William White, K. C. B., late assistant controller and director of naval construction at the Admiralty; Engineer-Rear-Admiral H. J. Oram, deputy-engineer-in-chief of the Navy; Mr. T. Bell, engineering manager of John Brown & Co., Clydebank, and Mr. A. Laing, manager of the Wallsend Slipway & Engineering Co., who have both had exceptional experience in the construction of the largest marine engines; Mr. H. W. Brock, partner in William Denny & Bros., Dumbarton, which firm has had the largest amount of experience with turbines applied for marine propulsion; and Mr. J. T. Milton, chief engineer surveyor of Lloyd's Register of Shipping; with Engineer-Lieutenant W. H. Wood,

R. N., who has for the last three years been secretary to the Admiralty boiler committee.

The commission has been dissolved, and, according to the official report, the members have recommended the adoption of the turbine.

The advantages and disadvantages of the turbine are fully discussed in the report, a new point under this head being that there is less saving of weight or area occupied than is usually understood to be the case. The machinery of the new ships, to maintain under all weather conditions a mean of 65,000 I.H.P., will be only 300 tons lighter than with reciprocating engines; but the commission counsel the Cunard Company not to rely on this saving to the extent of adding such 300 tons to cargo or other accommodation. It will be held in reserve in design for machinery. The one important disadvantage dwelt upon is the lack of economy at low speeds; but it is pointed out that as the new Cunarders, unlike warships, will always run at a uniform speed of 24½ knots, this should be considered a minimum in proportioning the turbines, so that at that speed the greatest power will be ensured, and then the coal and steam consumption should be superior to the reciprocating engines. Tests of land machinery on the turbine system, especially where superheated steam was used, showed a marked superiority in economy as compared with results in marine practice; but the only data possible in connection with marine turbines were deduced from trials with the English Channel turbine-propelled vessels. At full speed these showed a better economy by 2 per cent. than where reciprocating engines were used. The commission, however, are careful to point out that this result cannot be accepted as final in respect that there were several factors influencing efficiency which could not be eliminated, as, for instance, the form of the screw propellers. These vary results greatly. The form of the stern of the ship and the distance of the propellers from the hull are also disturbing factors; and importance is attached to these, although they were not within the scope of the investigations of the commission. Further tests are to be made with models at the Government tanks; but, apart from this one point, all the general

questions have been definitely settled. Economy, too, will result from the use of the turbine by the reduction of the staff in the engine room, and by the absence of lubricating oil in the exhaust steam.

The commission have recommended four shafts, not only because the four screws will give a higher efficiency, but because it was imprudent to divide the power through a less number of shafts. The commission considered the power necessary to give the sea speed of 24½ knots with various forms of hull, and although 24½ knots can be realized at sea under normal weather conditions, it is necessary to have a considerable margin of power to ensure that this rate will be maintained under adverse conditions; and for this reason 25 knots will be attained on an extended trial trip. Consequently, with three shafts, the power transmitted through each would require to have been about 25,000 I.H.P., whereas with four shafts it will not much exceed 18,000 I.H.P., which has already been adopted in one or two cases. There was also the question of the size of the turbine and the advantage of limiting the number of revolutions per minute of the screw propellers. Large diameter improves the sea maneuvering quality, and thus the committee started with the proposition that the revolutions should be limited to 140 per minute. This is considerably more than with reciprocating engines, but it compares with the 300 to 500 revolutions at which smaller turbine-driven vessels are now run.

*Type of Turbine.*—The design of turbine will differ slightly from that in other ships, and here I may say that the commission did not consider other systems than the Parsons, since there was no sea experience with others, so that Parsons' turbine will be used. Although the rate of revolution is commendably low, the turbines will require to be of great diameter to give the power, and the peripheral speed will consequently be very high, but no greater than with existing turbines.

The greater diameter of the turbines affects their arrangement in the machinery room of the ship. As recommended by the Commission, there will be one go-ahead turbine on each of the four shafts, which will be almost equidistant from each other.

The high-pressure turbines will be mounted on two outside shafts—an arrangement which enables the shafts to be far from the center of the ship without interfering with the lines of the hull. These shafts will have the propellers at a considerable distance from the stern of the ship, so that there will be the minimum of disturbance to the flow of water to the two inside propellers, which will be placed right-aft in the usual way. On each of the two inside shafts there will be two turbines. On each there will be the two low-pressure turbines for driving the ship ahead. The other two are for astern motion. It will be noted that the power for ahead motion is in two steam units, each with one high and one low-pressure turbine, giving the best expansion of steam; but should there be any breakdown of one shaft, turbine or propeller, the three remaining shafts may be run, and thus only one-fourth of the power will be unavailable. Since the turbine can be overloaded to a very much greater extent than the reciprocating engines, it will be possible to reduce this proportion of lost power very considerably, so that with a fractured shaft the sea speed may not fall short of the normal rate by more than a mile or a mile and a half per hour. Regularity is thus further ensured. Another advantage of the four screws and of the two central shafts being fitted with astern-driving turbines is that the power for driving astern will be equal to about one-half the forward motion power distributed through two shafts. And here, again, the possibility of an overloading of the turbines will add to the maneuvering qualities, and reduce the time and distance required for bringing the ship to a state of rest when running at full speed ahead.

*Boilers.*—The commission were not concerned with the boiler arrangements, but it is arranged that these are to be of the cylindrical type, with Howden's forced draft. The measure of the installation is found in the fact that, even assuming a high degree of economy, the coal consumption will exceed 1,000 tons per day. The one point to be determined is, therefore, the form of the stern and propeller brackets, a detail, but one of great importance in the cost of speed. This will not take more than a few weeks. It may affect the beam of the ship, so that this dimension

cannot be stated with certainty. The limits are between 85 and 88 feet. The length is fixed at 760 feet. It has not varied during all the investigations of the turbine commission. It is anticipated that a draught of 33 feet to 34 feet will be necessary when the vessel is laden with her coal supply for the voyage.

*Builders.*—The ships will be constructed one by John Brown & Co., Clydebank, and the other by Swan, Hunter & Wigham Richardson, Newcastle-on-Tyne, the machinery for the latter being supplied by the Wallsend Engineering Co. The contracts are not to be signed until the important question of breadth is decided, but preliminary work is being proceeded with, so that no time will be lost in completing the great enterprise. The commission, including engineers of ripe experience and progressive judgment, point out that many years have been needed to bring the reciprocating engine to its present high degree of perfection, and that little difficulties needing painstaking care may be involved in the great advance now proposed.

—"Practical Engineer."

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AN OFFICIAL "ARMY JOURNAL" IN ENGLAND.

The following special Army Order is quoted in full because of the varied criticisms it has aroused, even at this early date.

It is quite apparent from the wording of the order that the Army Council does not intend to leave a too free scope for discussion by contributors, and that the new "Journal" is to proceed upon very different lines from somewhat similar publications here.

THE ARMY JOURNAL OF THE BRITISH EMPIRE.

1. The Army Council have approved of the institution of a military publication to be called the Army Journal of the British Empire.

2. The journal is intended to deal with subjects of a professional and scientific nature, to encourage the study of military science and history, to circulate information on military matters, and to promote as far as possible a knowledge of the principles of Imperial defence amongst all ranks and all arms of the military forces of the Crown.

3. The Army Council hope and confidently anticipate that the journal will receive the fullest support from the entire British forces throughout the Empire.

4. Officers and soldiers of all services on the active, reserve or retired list of the military forces of the Crown in any part of the British Empire are invited to submit articles for insertion in the journal. Special articles by eminent civilian writers will also be published from time to time.

5. No payment for contributions will be made, but prizes will be granted from time to time for essays and articles on special subjects. Instructions regarding these prizes will be promulgated in the first number of the journal.

6. The following suggestions are given as a general guide to the nature of some of the subjects that might be dealt with by contributors:

(*a*) The discussion of new theories, discoveries or experiences in military matters; records of the progress of military science in British and foreign armies; historical memoirs or reviews; translations of, and extracts from, British and foreign military publications, provided that the necessary sanction for such translations and extracts has been previously obtained. Reports on foreign armies and expeditions; campaigning experiences and reports on special expeditions and journeys undertaken by British officers and men. Information regarding stations at home and abroad, with respect to climate, clothing, accommodation, currency and other local conditions which may be useful to officers and men quartered at, or proceeding to, such stations, etc.

(*b*) Reports on the results of various experiments in administration, organization, education, training, arms, equipment; staff rides, regimental tours, maneuvers, and other instructional operations and exercises of special interest, winter essays and lectures of exceptional merit, etc., provided they are submitted, in the case of officers and soldiers on the active list, through the usual official channel.

All contributions may, when necessary, be accompanied by a limited number of illustrations, plans, diagrams or photographs.

7. The journal will be published monthly.

The annual subscription will be 10s. 6d., exclusive of postage. The price of a single copy will be 1s. exclusive of postage.

The date of issue of the first number of the journal, and the name of the publisher and his agents at home and abroad from whom it may be purchased, either directly or through any bookseller, will be notified in a subsequent Army Order and announced in the Press.

Remittances should not in any case be sent to the War Office.

8. All contributions submitted for acceptance should be signed by the contributor, who, unless a civilian, should also give his rank, the regiment or corps in which he is serving or has served, and the appointment, if any, that he holds or has held in the military forces of the Crown, together with his postal address. In the case of non-commissioned officers and men, their regimental or corps number should also be given.

Contributors are requested to state, when forwarding their contributions, whether they wish their names to be published or not. Should they prefer their names to be withheld, the authorship of the contribution will be treated as confidential.

Anonymous contributions will be ignored.

All contributions (except as provided in paragraph 6, *b*) may be sent direct to the War Office (see also paragraph 17).

9. Criticism of official measures or regulations, matters of discipline, and other kindred subjects are not within the scope of the journal, nor can contributions of a personal nature be accepted.

10. Letters commenting on articles in previous numbers of the journal will, if considered suitable, be inserted.

11. No responsibility will be accepted for statements contained in any contribution which a contributor may submit.

12. Contributions which are found unsuitable for insertion in the journal will only be returned to the sender provided that a request to that effect accompanies such contribution, but no responsibility can be accepted for the loss of or damage to MSS., illustrations, drawings, &c. Although the journal may not appear for a few months, proposed contributions will be gladly

received at once, so that material for the first issues may be arranged forthwith.

13. All MSS. should be on one side only of the page. It should by preference be typewritten, but, if not, all proper names should be written in capital letters (or printed) to avoid mistakes.

14. Unless objection is expressly stated by the contributor, the right will be reserved of inserting summaries or extracts from articles submitted.

15. The source from which all non-original contributions have been obtained should always be stated.

16. Ordinary articles should not, as a rule, exceed 6,000 words, with three or four illustrations, plans, &c.

17. All contributions thould be addressed to the Chief of the General Staff, War Office, 68 Victoria Street, London, S. W., the words "Army Journal" being written on the left-hand top corner of the envelope.

By order of the Army Council,

E. W. D. WARD.

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MEETING OF INSTITUTE OF NAVAL ARCHITECTS.

The annual meeting of the Institute of Naval Architects of Great Britain was held in London, March 23 to 25 inclusive. The following papers were presented and discussed:

1. "The Battleships *Triumph* and *Swiftsure* (ex-Chilian *Libertad* and *Constitucion*)." By Sir Edward Reed, vice president.

2. "Merchant Cruisers and Steamship Subsidies." By the Right Hon. Lord Brassey, past president.

3. "On the Establishment of an Experimental Tank for Research Work on Fluid Resistance." By Sir William H. White, vice president.

4. "Some Results of Model Experiments." By R. E. Froude, member of council.

5. "On the Heeling and Rolling of Ships of Small Initial Stability." By Professor A. Scribanti, R. Ital. N. R., member.

6. "Gyroscopic Effect of Fly Wheels on Board Ship." By Herr Otto Schlick, member.

7. "Some Advantages of Gas and Oil Engines for Marine Purposes." By J. E. Thornycroft, associate.

8. "Internal Combustion Engines for Propelling Small Vessels." By A. F. Evans, visitor.

9. "Steam Turbine Propulsion for Marine Purposes." By Professor A. Rateau, of Paris.

10. "Some Points in Connection with the Transverse Strength of Ships." By J. Bruhn, member.

11. "Normal Pressures on Thin Moving Plates." By A. W. Johns, visitor.

12. "Ships' Composition." By A. C. A. Holzapfel, associate.

13. "Fire Prevention on Ship Board." By Edwin O. Sachs, associate.

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### THE MANAGEMENT OF BELLEVILLE BOILERS AT SEA.

At a meeting of the North-East Coast Institution of Engineers and Shipbuilders, Engineer-Lieut. E. F. Baker, R. N., read a paper on "The Management of Belleville Boilers at Sea," giving the result of the experience gained with these boilers in the *Good Hope*, cruiser.

Engineer-Lieut. Baker said that so much had been said to the discredit of the Belleville boilers that one wondered how it was that ships fitted with them were able to steam at all, and yet vessels fitted with Belleville boilers set out on voyages to all parts of the globe, and not only reached their destinations and came back again, but were ready to repeat the programme. That there was a certain amount of perversity about the Belleville boiler could not be denied, but it had been proved over and over again that, so long as it was reasonably treated, it would do its work in return. There were in the cruiser *Good Hope* 43 Belleville boilers, designed for a pressure of 300 pounds to the square inch, and fitted with economizers. In ordinary conditions a pressure of from 225 pounds to 250 pounds of steam was kept in the boilers, giving from 200 pounds to 225 pounds pressure in the engine room.

When the ship was first commissioned the maintenance of steam and the details as to cleaning fires were in a large measure

left to the chief and leading stokers, who received their orders from the officer of the watch as to the pressure to be kept, the thickness of the fires, and the number of fires to be cleaned each watch. As the ship was not fitted with reducing valves, like some of the earlier Belleville ships, this arrangement proved unsatisfactory. Most of the men, having just come out of ships fitted with cylindrical boilers, treated the Belleville boilers as they had been accustomed to treat the former. When the pressure dropped everybody fired up, with the result that it went up with a run, as also did the coal consumption, and this method of stoking was accompanied by clouds of smoke. Then the firing would cease, and in a short time the pressure would drop as fast as it had risen, and the same performance would be repeated, with the same unsatisfactory results. Again, the men would wait until the pressure was up before cleaning fires, when several would be started at once, with the natural result of a rapid falling of the pressure; and then some of the fires would be scamped, and the next watch would have more than their proper share to clean, and probably the steam would be down all the watch. The variation in the steam pressure and the consequent irregularity of the speed, as well as the quantities of smoke made, were at times considerable, owing to the difficulty of effectually controlling the working of the boilers. The irregularity in the steam pressure in these conditions was not surprising when one compared the quantity of water under treatment in the cylindrical and Belleville boilers respectively. The ratio of the quantity of water under treatment in the Belleville boiler to that in the cylindrical boiler was as 1 to 8.42. The large volume of water in the cylindrical boiler performed a function similar to that of the fly-wheel in the engines, in that it stored up the surplus heat energy above that actually required, with a slow rise of pressure, and gave it out again when required with a slow fall. The difference showed the necessity for more system and regularity in the treatment of the Belleville boiler, which was only possible with a thorough control of the firing and cleaning. To control the firing the first thing necessary was to determine the quantity of coal required to be burnt

at the different speeds. Engineer-Lieut. Baker described the method adopted for ensuring regularity of stoking and the cleaning of the fires.

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### PAINTING BRONZE PROPELLERS.

The following is an extract from a paper on "Ships' Composition," read before the Institution of Naval Architects, by Mr. A. C. A. Holzapfel:

"While I am on this subject, I might also refer to the question of bronze propellers. I find that shipowners are not in the habit of coating these with composition, although nearly all varnish paints adhere well to every part of a propeller, except about a square foot on the back of each blade, where the dead water gathers and where they wear off. I frequently notice that these bronze propellers are covered with grass or small acorn shells, which fact must considerably detract from their efficiency and from the vessel's speed. I also notice that pieces of zinc are fastened close to the stern to exhaust the galvanic current which forms between the iron of the ship's hull and the bronze propellers, and which would otherwise damage the ship's hull. It is natural that while a galvanic current exists between the bronze propeller and the ship's hull or the zinc plates attached to the ship, the bronze of the propeller ceases to disintegrate or to be anti-fouling, and that it will be covered with a growth if the vessel is in a fouling port. By applying the usual two coats of varnish paint, this fouling of the propeller can be prevented, and, moreover, the strength of the galvanic current set up between it and the ship's hull can be reduced to a minimum, as the exposed surface of bronze would be only 2 per cent. or 3 per cent. of what it is when the propeller is not painted. For this reason it must be apparent that bronze propellers should invariably be painted with anti-fouling composition. If it is desired to have these compositions of a light color, manufacturers could, no doubt, supply a special light-colored composition, which would adhere as well as the others."

ENGINE ROOM CONDITIONS.

During the consideration of the British naval estimates the discussion was opened by Sir Charles Dilke, who referred to "the extraordinary proportion of breakdowns of cruisers during the last maneuvers." "Engineering" comments on this subject as follows: "What we have always held to be the true cause of most failures of this nature was given by Mr. Pretyman on Monday in his speech on the general motion. 'The troubles that arise,' he said, 'the breakdowns of machinery and mechanism, occurred almost invariably in ships specially commissioned with active-service ratings to take part in the maneuvers.' It is satisfactory to get this official recognition of a serious blot in our naval administration; but we would go much further than Mr. Pretyman. The way in which engine-room complements are shifted about, and taken from their legitimate duties in arbitrary fashion, is a leading cause of accident and inefficiency. Perhaps twenty years or so later, when executive officers have become engineers, there may be more appreciation, not only of the importance, but of the intricacy of the mechanical work on shipboard. As it is, engineer officers are constantly reduced to despair by losing their men in the midst of important operations. This applies more especially to work carried out on ships refitting in the dockyards and of the reserve.

"It is, perhaps, not unnatural for an executive officer who knows nothing of engineering matters to conclude that a stoker is a stoker, or an artificer an artificer, without distinction—one as good as another, and all fit for the job; but engineers know there is a difference. No two ships, even sister ships, are alike, just as no two men are alike. Cutlass and rifle drill may be ground by practice to absolute uniformity; but engines need humoring, even the best. The senior engineer gradually finds by experience the right man for the right place—the men he can depend upon for a critical position; and the critical position differs in all ships' machinery, as it would always do, even if all machinery were made in the same shops off the same drawings. That is a thing the drill officer on deck never remembers when he curses the stupidity of the awkward lot in the engine room. These things

are not of vital importance in maneuvers; but with the real thing they would mean catastrophe."

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### TRAINING OF ENGINE ROOM ARTIFICERS.

The work of transforming the *Bellerophon* and *Temeraire* to meet the Admiralty scheme for the training of engine-room artificers at Devonport has been almost concluded by Palmer's Shipbuilding and Iron Company, Jarrow-on-Tyne; and the *Bellerophon* will leave the Tyne, for Devonport, on Tuesday next, and the *Temeraire* soon afterwards. The *Bellerophon* was launched in 1865, and the *Temeraire* was commissioned in 1877, and both were nearing the period of obsoleteness. The *Bellerophon*, as altered, has accommodation for 200 boys, 160 crew, and 40 instructors. She will lie at Devonport with the *Temeraire* and the *Indus;* the *Indus* being a floating factory, and the *Temeraire* supplying electricity for lighting and power to herself and the other two vessels. All three will be connected by bridges. The engines and four of the boilers have been taken out of the *Bellerophon*, and the interior has been fitted for the purpose for which the vessel is intended.

On the upper deck, from side to side, a great workshop of corrugated iron has been set up, 200 feet long and 50 feet wide, and this has been filled with machinery of all sorts for the instruction of the youths as fitters, turners, boilersmiths, coppersmiths, &c. Boys are to be taken at the ages of from 14 to 16, and the new system will take the place of that under which men from 21 to 28 were engaged for the service after having served five years in a shore factory. A gymnasium, drawing office, model room and other apartments are under the same roof as the workshop, and on the decks below are class rooms, recreation room and others. The portion of the stokehold from which the boilers have been removed is now occupied by a very complete smithy, containing twenty-one furnaces and a 2½-cwt. hammer driven by pneumatic power and electricity. The men's quarters are entirely separated from the boys'. The work of transforming the *Bellerophon* was begun on January 21, and has

been completed in a remarkably short time. The *Temeraire* has been greatly modified. Her engines have been taken out bodily. Two dynamos have been fitted, each capable of producing 450 ampères at 220 volts. The current drives seven motors, varying from 7 to 20 horsepower, and lights 1,200 lamps in the three ships. The three vessels—the *Bellerophon*, *Temeraire* and *Indus*—will lie tandem. The work has been designed and carried out under the personal supervision of Engineer-Captain George A. Haddy. The cost of altering the two vessels has been over £30,000.

The refitted ships are to be renamed *Indus II* and *Indus III.*

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## STEAM TURBINE PROPULSION FOR MARINE PURPOSES.*

By PROFESSOR A. RATEAU, of Paris.

There is no need, in a country which has given birth to the Parsons turbine, to insist upon the interest attached to the application of the steam turbine to the propulsion of ships. The remarkable results which the distinguished inventor of that engine has obtained are matters of common knowledge, and the author is one of those who have most admired and appreciated the methodical manner in which these results have been achieved. Mr. Parsons has himself set them forth in the paper which he read before the Institution at the last summer meeting.

This important question has also attracted much attention in France for several years past, and I propose, therefore, to give the results which have been so far attained there. If these results are but slender, it is due to the fact that the means at our disposal have not been sufficient to enable more progress to be made.

There are, at the present time, two ships fitted with our turbines, namely, the French torpedo boat No. 243 and a first-class torpedo boat built by Yarrow & Co. The latter alone has been constructed according to our ideas, as the restrictions imposed by the naval authorities upon the French torpedo boat, and the

* Read before the Institution of Naval Architects, London, March 25, 1904.

conditions laid down for its propellers have created such difficulties that it has been impossible up to now to obtain a satisfactory speed with this vessel. It was, however, only a trial boat, and the speed was not required to exceed 20 knots. In point of fact, we have obtained over 21 knots. With Yarrow & Co.'s boat, on the other hand, the conditions are such as to utilize the full value of the turbines, and the latter have been further supplemented by a small reciprocating engine for economical working at reduced speeds. The trials with this boat are, therefore, of considerable practical interest, and I have much pleasure in acknowledging our debt to Mr. Yarrow for the breadth of view which he has shown in dealing with these new conditions.

Another small vessel, the *Libellule*, was to have been fitted with a turbine of our manufacture, and the engine has been completed for some time past, but the trials have not yet taken place, as the special boiler with which it was desired to make the experiments was not ready.

Before going into details of each of these applications of our system of turbine, it may be well to set forth some of the obstacles which arise in using turbines for the propulsion of vessels; obstacles which in the author's opinion, can only be satisfactorily overcome by a joint use of reciprocating engines and steam turbines.

As to the advantages of turbines, these are well known; absence of vibration, great reduction of weight, ease in handling, absence of wear and tear, etc. There is no need further to insist upon them.

The three principal difficulties in applying turbines to the propulsion of ships are as follows:—(1) Design and arrangement of propellers for a high speed of rotation; (2) Efficiency of turbines at low speeds; (3) Reversing and maneuvering powers.

(1) Arrangement of Propellers for a High Speed of Rotation.

When the turbines are not restricted to any particular speed of rotation, a very high efficiency can be obtained, certainly higher than that of the best reciprocating engines.

The author's experiments confirm this fact, which had already been shown by the published trials of the Parsons turbine. Unfortunately the best speed for turbines is usually much too great for screw propellers. In high-speed vessels, by some give and take between engine and propeller, a working agreement can be arrived at; but it is not easy to do. The gearing of the rings has to be higher than with a turbine for other purposes, and the turbine itself must be divided up into several sections in series, and, further, it is necessary to devise some arrangement for the propellers by grouping them either singly, in pairs, or in threes on several shafts, and to so increase their surfaces that the extreme outside diameter shall be greater than the pitch, all of which tends to reduce the total efficiency of the engine and propellers.

If, therefore, the turbine is theoretically superior to the reciprocating engine as regards consumption of steam at full speed, it is not by any means certain *a priori* that the joint efficiency of both engine and propeller is better or even as good.

The practical difficulties, moreover, increase as the speed diminishes, for in the first place the total surface (and consequently the size of the propellers) is mainly determined by the principal cross-section of the ship, whereas, on the other hand, the size of the turbines is limited only by the speed of rotation, and not by the power developed. The speed of the turbine must be reduced in proportion to the speed of the ship, so that the dimensions of the former are increased, either by the number or the diameter of the moving rings, whilst the power diminishes approximately as the inverse of the cube of the speed. There is, therefore, a lower limit of speed, below which the use of turbines cannot be recommended. The author has already expressed the opinion (in a paper read before the Association Technique Maritime in 1902) that this limit is in the neighborhood of 20 knots. The author is aware that certain ships now under construction for transatlantic service, and of a proposed speed of 17 knots, are being fitted with turbine engines, but the future will show how these will turn out.

(2) Efficiency at Low Speed.

If the steam turbine is capable of giving good results at the maximum power, it cannot be gainsaid that the results are certainly unsatisfactory at reduced speeds, not so much on account of the reduction of power, as on account of the reduction in the speed of rotation, which involves a lowering of what is termed the "hydraulic efficiency" of the turbine. The increase in the coal consumption at speeds of, say 12 to 15 knots, at which they are usually working, would, however, greatly diminish their radius of action. A partial remedy, as used by Mr. Parsons, may be effected by adding a supplementary turbine for cruising purposes, into which the steam first enters when proceeding at low speeds. This, however, does not improve the hydraulic efficiency of the turbine, and the steam consumption, nevertheless, remains high.

The author considers that under no circumstances can turbines alone be economically worked at low speeds, and that the only satisfactory solution is the employment of a reciprocating engine of more or less power, according to the circumstances, in conjunction with turbines. With this combination, economical results can be obtained at all speeds, and an example of this will be given later.

(3) Reversing and Maneuvering Powers.

With a reciprocating engine, stopping and reversing are effected in the simplest possible manner, whereas, the very principle of the turbines is essentially opposed to this. Various inventors have tried to solve this problem by means of special blades to enable the same rings to be used for both directions of motion, but these attempts do not appear likely to come to anything, as one can only obtain reversibility by a considerable sacrifice of efficiency in forward motion. It is, therefore, necessary to supplement the turbine by special engines for going astern, and, as it is obviously impossible to have the latter as powerful as the former, one must be satisfied with a very much smaller speed astern than ahead. This difficulty in freely going astern makes maneuvering very awkward. The engine for going astern may

be a reciprocating one, which would also be of use for going ahead, but it can just as well be a steam turbine. From the very start, Mr. Parsons used in his vessels special turbines for going astern, and these were attached to the same shafts as the main turbines; but this arrangement has the inconvenience of taking up a good deal of space lengthways.

In my patent of 1898 I have indicated how these can be fitted so as to be, as it were, hidden inside the main turbines on the low-pressure side, and without taking up any additional space. When they revolve freely, the astern rings offer no appreciable resistance while the main turbine is at work, and, conversely, the latter is idle when the astern turbine is in motion. This is the arrangement we have got in torpedo-boat No. 243 and in the *Libellule*, and it has the advantage of great simplicity. I think that Mr. Parsons has also made use of a similar arrangement in a certain number of his recent vessels.

According as the astern turbine is more or less developed, so the astern speed is more or less increased. With a single live ring, as on torpedo-boat No. 243, and for the same expenditure of steam, the stern speed will be about 40 per cent. of the speed ahead, but with two rings it can be increased to 50 per cent. Adding more rings, however, adds very little to the speed, unless the number is so greatly increased as to make this engine almost as important as the principal one.

For quickly stopping a vessel, turbines are apt to be inconvenient. After steam is cut off, the propellers continue to revolve by the action of the water, and they usually carry around with them the live rings, for the resistance to rotation is very slight. One can, however, increase this resistance by admitting steam in the opposite direction on the astern rings.

This question of stopping, reversing, and maneuvering is one which, in the author's opinion, may prove a serious hindrance to the extensive use of turbines for ship propulsion. It is particularly important for warships to be able to maneuver with ease, and it will necessarily lead to the adoption of a combined system of turbines and reciprocating engines.

COMBINED USE OF TURBINES AND RECIPROCATING ENGINES.

For the various reasons given above, the best solution appears, therefore, to be the simultaneous employment of a reciprocating engine and turbines attached to independent shafts, in order that the reciprocating engine may be used at any speed. Each kind of engine is thus adapted to the work which suits it best. The reciprocating engine does for slow speeds, while the turbines come into play progressively as the higher speeds, up to the maximum, are required. They can, moreover, be equally well arranged for going astern, and the combination of the two then makes maneuvering almost as easy as with ordinary twin screws. An effective horsepower astern of 75 per cent., or more, of that when going ahead can thus be obtained.

The power of the reciprocating engine should not be less than one-sixth of the total, and it can quite well be increased to one-third or even to one-half of the maximum horsepower. It may be urged that this arrangement is complicated, and that if such an important reciprocating engine is to be retained, it is better to stick to the present system. In reply to this objection, however, the following advantages may be shown: (1) Reduction of weight, although rather more space is taken up in plan; (2) easier working and maintenance, and subsequent saving in personnel; (3) reduction of the vibration due to the reciprocating engines; (4) increased efficiency, as the turbine is particularly suited to utilize the expansion of steam up to its extreme limit. It may be estimated that the increase in power for the same consumption of steam would amount to 15 to 20 per cent., or, in other words, that 5 or 6 per cent. increase of speed would be obtained by the arrangement here proposed.

Moreover, this arrangement will make it possible to bring the turbines advantageously into play at a lower limit of speed. With turbines alone, this limit is about 20 knots, whereas with the combined system it is possible to begin at 15 knots or perhaps even less.

Mr. Parsons, in a paper read before the Institution of Shipbuilders and Engineers in Scotland, on "The Marine Steam

Turbine and its Application to Fast Vessels," spoke of the speed of rotation of turbines falling when at reduced speed within the limits of those at which reciprocating engines can work, and he proposed to attach the latter on the same shafts as the main turbines, and have both work side by side. At reduced speeds these triple-expansion reciprocating engines would receive steam straight from the boilers, and expand it to, say, atmospheric pressure. The steam would then pass into the high-pressure turbine, and thence into the low-pressure turbine before reaching the condenser. When the power and speed are such that the speed of rotation rises above the limit for reciprocating engines, the steam will be cut off from the latter, and the turbines alone will propel the ship. With this arrangement, the reciprocating engines would, therefore, be useless at the very time when the greatest power is required, and there would, further, be a chance that the engineers might not throw the engines out of gear at the right time, and so cause an accident. This direct coupling of engines, essentially adapted for very different speeds of rotation, is obviously unsound. The only rational arrangement, in the author's opinion, is to make the reciprocating engine mechanically independent of the turbine, by having it act on a shaft and propeller of its own. But as regards the supply of steam, this can be combined in various ways with that of the turbine, either side by side, as in Messrs. Yarrow's boat, or in series, by having the steam begin on the reciprocating engine and complete its expansion in the turbines. A special combination of this kind, quite different to those already suggested by Mr. Parsons, is what the author advocates.

### Results Obtained with the Rateau Turbine.

*Description of the Engine.*—The author's design of turbine has already been described in several publications. It need only be stated that it consists of a series of flat moving rings, varying in number according to the requirements, and fitted on a single shaft. These rings are placed between circular discs whose rims fit into grooves on the inside of the casing. The shaft traverses these diaphragms through bushes, which allow but little play.

Elsewhere, the clearance between the moving and the fixed parts generally exceeds 3 mm., and can even be as much as 5 or 6 mm. without causing trouble. With this arrangement, and by using the work by "impulse" instead of work by "reaction," we have sought to obtain an engine using as little steam as possible, simple in construction, needing but little care in working, and capable of running for a long time with but little wear and tear, which, although inevitable, can yet be reduced to a very small amount. The loss of steam is entirely confined to the clearance allowed around the shaft. Moreover, the live rings are so constructed as to be very light, and this is of advantage in reducing the gyroscopic effect which comes into play when the vessel pitches.

It has been said that with this system, supposing one could reduce the loss of steam to a minimum, it would, on the other hand, greatly decrease the efficiency by the friction between the rings and the steam contained in the chambers in which the rings rotate. As a matter of fact, however, the friction in our engines of 1,000 to 2,000 H.P. amounts to only 2 or 3 per cent. of the maximum power—an insignificant proportion—whereas in turbines without diaphragms the loss by the escape of steam reaches 10, 15, and even 20 per cent. of the maximum horsepower, directly the clearances increase at all. All the trial results so far obtained show that our system of turbine is extremely economical in steam consumption. Here are a few of the principal results obtained:

*Turbines of the Torpedo Boat No. 243.*—These were the first multicellular turbines which have been constructed from our designs by Messrs. Sautter-Harlé & Co., in Paris. These turbines were designed some five years ago, and several improvements have been since effected which considerably diminish the consumption of steam.

A turbine exactly similar to the one installed in torpedo boat No. 243 was tried under the direction of the French Admiralty engineers in the workshops of Messrs. Sautter-Harlé & Co. This engine was coupled to a three-phase alternator, so as to measure exactly the effective horsepower of the turbine. The electric cur-

rent generated was taken up by liquid resistance. As the losses of energy in the alternator had been measured, it was possible to calculate the net effective horsepower of the turbine, and consequently its efficiency. By the "efficiency" of the turbine is meant the ratio of the effective power which it develops on the shaft to that which the steam consumed is capable of giving, assuming that there is no loss between the pressure at admission and the pressure at exhaust into the condenser. This experiment gave a result higher by 1 per cent. than had been originally estimated viz: 54 per cent. instead of 53 per cent. The curves there drawn are obtained by reducing the speed of rotation to the uniform speed of 1,700 revolutions per minute, and the condenser vacuum to 26 inches of mercury. It will be seen that at full power, with a steam pressure at admission to the turbine of 145 pounds per square inch, the consumption per effective horsepower on the shaft is 15.2 pounds. At the normal speed of 1,800 revolutions per minute, for which the engine was designed, the efficiency is rather higher, and the steam consumption rather lower.

We can now make engines of this power with 60 per cent. or even 70 per cent. efficiency, according to the speed of rotation which can be used for the turbines, depending on the use for which they are designed.

The turbine for the Yarrow boat has not yet been tested at the works up to its full speed, but from previous calculations it is estimated that the efficiency should be 61 per cent. at a maximum of 2,000 horsepower, with a normal speed of 1,500 to 1,600 revolutions per minute. The loss due to friction between the rings and the steam is only 41 horsepower, or 2 per cent. With 170 pounds per square inch pressure and a vacuum of 27 inches, the consumption of steam of this engine is $\frac{8.2}{0.61} = 13.4$ pounds per effective horsepower hour, which corresponds to 11.7 pounds per indicated horsepower for a reciprocating engine having 12 per cent. loss due to internal friction.

Other turbine-driving alternators, continuous-current dynamos, centrifugal pumps or fans, and constructed by Messrs.

Sautter-Harlé have been carefully tested, and among the results obtained I would call attention to the following :—

An engine of 600 horsepower, at 2,400 revolutions per minute, consumes 14.6 pounds per electrical horsepower per hour. The efficiency of the dynamo being 91 per cent., it follows that the consumption of steam for the turbine was 13.3 pounds per effective horsepower hour, or 11.3 per indicated horsepower hour, assuming the efficiency of the reciprocating engine to be 85 per cent., the steam pressure at admission being 142 pounds and the condenser vacuum 26 inches.

An engine of 350 horsepower, driving an alternator at 3,000 revolutions per minute, showed a consumption of 26.2 pounds per kilowatt generated by the alternator (including exciter) the steam pressure at admission being 152 pounds, and the condenser vacuum only 24 inches. The efficiency of the alternator being 87 per cent., this corresponds to a steam consumption of 14.1 pounds per indicated horsepower hour. It will be seen that this was a case of a relatively weak engine working with a very poor condenser vacuum.

A low-pressure turbine of 350 H.P., installed in a mine at Bruay, gave an efficiency rather higher than the above, the total efficiency of the turbine and dynamo combined reaching 58 per cent., or for the turbine alone 63 per cent. Recent tests have shown that the efficiency of this engine has remained the same after a year and a half of continuous work, and no appreciable increase in total steam consumption for the same amount of energy produced has been observed.

A turbine pump of 500 H.P., for raising 950 gallons per minute to a height of over 1,200 feet, and which was recently tested, gave a consumption of 22.5 pounds per horsepower hour in actual water raised, the pressure at admission being 90 pounds per square inch, and the condenser vacuum 26 inches. The efficiency of the pump being 70 per cent., this corresponds to an efficiency of 61 per cent. for the turbine. In all the above cases the steam was not superheated.

It will be seen from these examples that even for engines of only 300 to 600 H.P. a working efficiency of over 60 per cent.

can be obtained, while for engines of 1,000 H.P and over, it is certain that upwards of 65 per cent. efficiency can be realized, as already stated. Hence it is easy to arrive at the consumption of steam per effective horsepower under various circumstances, by using the formula which I have already given. For instance, we could guarantee that for an engine of 5,000 to 6,000 H.P., supplied with steam at 150 pounds, and superheated to 350 degrees Centigrade, with 28 inches vacuum, the consumption per effective horsepower would not exceed 9.6 pounds, which corresponds to 8.6 pounds per horsepower hour, assuming 10 per cent. to be lost in internal friction.

In order to properly understand the value of these figures, it is necessary to compare them with those obtained with reciprocating engines. When the expansion of steam in the cylinder has been carried sufficiently far, which occurs at from one-half to two-thirds of full power, the efficiency of powerful reciprocating triple-expansion engines is as much as 62 per cent. (this is net efficiency; that is to say, the ratio between the work performed on the shaft and the work that the same amount of steam would give with no loss). But this is not the case when the engines are working at full power, for then, in order not to increase the weights too much especially on warships, one must increase the admission to the cylinder up to and even beyond 70 per cent. From an investigation made by Mr. Lelong, a French Admiralty engineer, published in the Transactions of the Association Technique Maritime (1899), the efficiency in work delivered on the pistons of several engines of from 3,600 to 8,400 horsepower, varies from 51.7 per cent. to 57.8 per cent., or an average of 55.2 per cent. (*Carnot, Charles-Martel, du Chayla, Galilée, Lavoisier.*) Deducting therefrom 8 per cent. for internal friction losses, this would leave 51 per cent. for the net efficiency, whereas, from what has been said above, steam turbines can easily yield over 60 per cent. net efficiency when working at full power.

I will now give a few details of the application of these turbines to ship propulsion.*

* There are, at the present time, either in use or in process of construction, over 50 turbines of the Rateau design, with an aggregate of 25,000 horsepower, of which 6,200 horsepower are used for ship propulsion, 950 horsepower for turbine pumps, and 760 horsepower for turbine fans.

TORPEDO BOAT No. 243.

Five years ago, in 1898, the French Admiralty began to experiment with steam turbines for the propulsion of warships. Knowing that we had already given attention to this question, the Admiralty invited Messrs. Sautter-Harlé and the author to supply engines of this kind for a torpedo boat of 92 tons. The object of the experiment was also to investigate the working of combinations of propellers. In order to reduce expenses, it was laid down that the hull of an ordinary torpedo boat should be used, and that the turbine should be installed in the space usually occupied by the reciprocating engines, in order to allow the latter to be replaced in position, if necessary, at the end of the experiment. This arrangement caused a great deal of inconvenience in the installation of the turbines and propellers, and it ultimately resulted in the trial not being so conclusive as it should have been. It was naturally very difficult to adapt turbines to a hull designed for a reciprocating engine, as the cross-section of the boat has a distinctly V-shaped outline in its lower part, whereas, for the turbines, which have to be arranged one on each side of the center line, the cross-section should have been much flatter on the floor. Hence the impossibility of sufficiently lowering the main shafts where they enter the turbines, which involved their being very steeply inclined, viz: 11 per cent. off the horizontal. Each shaft carried three propellers, and was supported at two points by long brackets fixed to the hull.

These conditions were very unfavorable, the steep inclination of the shafts operating against the efficiency of the propeller, and this was fully brought out in the trials; while the excessive length of the brackets aft considerably increased the total resistance of the vessel. As regards the turbines themselves, they have given very satisfactory results, as shown in the reports of the trials. The two turbines, of 900 H.P. (nominal) each, are quite independent of one another. On the exhaust side they enclose a single moving ring for going astern, and in this first attempt we voluntarily sacrificed power in going astern. The chief object, as has been stated, was to see if the combination of turbines and small propellers could give the vessel anything like the speed

she would have obtained with reciprocating engines. In point of fact, 21 knots only was the speed obtained, whereas it should have been 24 knots, as the turbines themselves gave rather more power than had been estimated, and this difference is principally attributable, as already stated, to the steep sloping of the propeller shafts.

At the first trials, we had some trouble with oil getting into the condenser. This arose from having designed a joint of oil under pressure at the point where the shaft enters the turbine on the low-pressure side. This joint effectually prevented the ingress of the air but caused a considerable flow of oil to the condenser. To remedy this, we put the low-pressure bearing completely outside the turbine, and used a novel system of packing. As to the other bearings, one at the middle of the shaft and the other at the high-pressure end, they both remained inside the turbine. Lubrication was effected by pumping in oil from the outside, and the excess oil afterwards collected.

TABLE A.—TORPEDO BOAT NO. 243. TRIALS OF 22D JANUARY, 1903.

Six propellers: Diameter, 23.6 inches; pitch, 19.7 inches.

| Number of trial. | I. | II. | III. | IV. |
|---|---|---|---|---|
| Speed of vessel (in knots)—mean of 3 runs.. | 17.07 | 19.59 | 20.94 | 21.26 |
| Rotation of turbines—revs. per minute..... | 1,348 | 1,572 | 1,748 | 1,774 |
| Effective pressure of steam on admission to turbines—lbs. per square inch..... | 68.26 | 100.98 | 129.42 | 132.26 |
| Condenser vacuum—inches..... | 28 | 28 | 27 | 27.5 |
| Mean slip of propellers..... | .217 | .23 | .26 | .26 |

With the other arrangement of propellers the following results were obtained:

TABLE B.—TORPEDO BOAT NO. 243. TRIALS OF 6TH DECEMBER, 1902.

Propellers: Diameter, 20.9 inches; pitch, 23.6 inches.

| Number of trial. | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| Speed of vessel (in knots)—mean of 2 runs. | 14.9 | 16.59 | 18.73 | 18.83 | 20.89 |
| Rotation of turbines—revs. per minute..... | 1,051 | 1,213 | 1,386 | 1,392 | 1,556 |
| Effective pressure of steam on admission to turbines—lbs. per square inch..... | 104.5 | 80 | * | 99.5 | 115 |
| Condenser vacuum—inches..... | 26.4 | 26.4 | 26 | 26.4 | 26.8 |
| Mean slip of propellers..... | .279 | .304 | .311 | .311 | .316 |

* Owing to the failure of the gauges the pressures in the turbines could not be taken on this trial.

The torpedo boat No. 243 was built by the Societé des Forges et Chantiers de la Méditerranée at Havre, where its trials were run.

After the alteration in the low-pressure bearing, the engines worked very satisfactorily, and, although each turbine now has two internal bearings, the leakage of oil to the condenser is very slight, and compares favorably in this respect with a reciprocating engine. Since July, 1902, there have been a large number of trials with this boat in the presence of French Admiralty engineers, and no less than six different arrangements of propellers distributed in pairs or by threes in each shaft have been tried. The speeds obtained have varied greatly, according to the arrangement of the propellers, but at full power the highest speed varies from 18 to 21 knots, corresponding to a variation of efficiency of 40 per cent. The full details of these trials cannot be given here. I will, however, give the results of two trials made with propellers of 23.6 inches pitch and 20.9 inches diameter in one case, and 19.7 inches pitch and 23.6 inches diameter in the other. The first trials are summarized in Table A.

BOAT BUILT BY MESSRS. YARROW & CO.

The author's system of turbines has been installed on the vessel built by Messrs. Yarrow & Co. She is a sister ship to the *Tarantula*, which, as is well known, was fitted with a Parsons turbine, and is similar, apart from the system of propulsion, to the first-class torpedo boats of the British Navy. Displacement, 140 tons; length, 152 feet 6 inches; breadth, 15 feet 3 inches.

The boilers, of the well known Yarrow type, are the same as are usually fitted on first-class torpedo boats, and are capable of giving a maximum speed of from 26 to 27 knots with ordinary reciprocating engines.

The boat here described was fitted with three propeller shafts, actuated simultaneously and separately by turbines and a reciprocating engine; the latter (of 250 horsepower) works the central shaft, and is quite independent of the turbines, receiving steam directly from the boilers, and exhausting directly into the condenser. This central shaft only carries one propeller, which is 4 feet in diameter.

The side shafts, which are arranged to carry either one or two

propellers each, are worked by a turbine in two sections, arranged in series, and rotating in opposite directions. The supports for the thrust bearings have been increased in order to take the full thrust of the propellers. This thrust being nearly balanced by that of the steam on the drum inside the turbine, it would have been quite possible to reduce the bearings by one-fifth.

The combination of reciprocating engine and turbine, as adopted by Mr. Yarrow, had already been advocated by Mr. Nabor Soliana, director of the Ansaldo Works, Genoa (see "Engineering," 28th March, 1902). But this is not the only possible arrangement, and an even better one, in the author's opinion, is, instead of letting the reciprocating engine exhaust directly into the condenser, to lead the exhaust steam into the low-pressure turbine, or even, under certain circumstances, into the high-pressure turbine. The author had previously arrived at this conclusion as being the only rational arrangement for economical working at slow speeds.

The turbines were built at the Oerlikon Works in Switzerland.

The total weight of the turbines, which are capable of giving upwards of 2,000 H.P., is 17,200 pounds, or 8.6 pounds per horsepower, and this could be reduced by diminishing the thickness of the turbine casings which have been made unnecessarily heavy, and by suppressing the supports of the thrust blocks.

At the point where the shafts pass through the ends of the casing, watertightness is obtained by the same system of packing that is employed with land turbines. A special regulator governs the pressure on the four glands so as to prevent any access of air. With this arrangement it is easy to obtain a good vacuum in the condenser, and one of the two air-pumps originally installed has consequently been suppressed. As will be seen in the following table, the vacuum has, with a single-air pump, been kept constant at 27 inches at all powers.

Several trials have been made with this boat from 13th October, 1903, up to quite recently, and the author was present at

some of these trials, which were under the immediate supervision of Mr. Marriner, chief engineer to Messrs. Yarrow & Co.

*First Trials.*—The first trials were made on 13th October, 1903, each propeller carrying a single screw of three blades of 32 inches diameter and 30 inches pitch. Table C gives a summary of the results obtained by progressively increasing the pressure of steam supplied to the high-pressure turbine. In the first run no steam was supplied to the turbines, the reciprocating engine alone being employed, and the turbines turning idly by the action of the water on the propellers.

TABLE C.—MESSRS. YARROW & CO.'S TORPEDO BOAT. TRIALS OF 13TH OCTOBER, 1903.

Wind rather strong.

| Number of trial. | | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|---|
| Number of runs on measured mile | | 3 | 2 | 2 | 2 | 3 |
| Effective pressure of steam on admission to H.P. turbine—lbs. per square inch | | ... | 5 | 50 | 100 | 145 |
| Condenser vacuum—inches | | 26.8 | 28 | 28 | 27.2 | 26.9 |
| Speeds attained in various runs (knots) | | 10.68 | 17.39 | 20.66 | 23.84 | 27.69 |
| | | 13.5 | 13.7 | 16.76 | 20 | 22.36 |
| | | 10.3 | ... | ... | ... | 27.48 |
| Mean speed of vessel (in knots) | | 11.98 | 15.54 | 18.71 | 21.92 | 24.97 |
| Rotation of reciprocating engine—revs. per minute | | 369 | 411 | 441 | 475 | 516 |
| Rotation of H.P. turbine—revs. per minute | | 393 | 688 | 955 | 1,172 | 1,455 |
| Rotation of L.P. turbine—revs. per minute | | 395 | 687 | 994 | 1,357 | 1,657 |
| E.H.P. developed on shaft of reciprocat'g engine | | 239 | 260 | 251 | 235 | 232 |
| Slip of propellers | Recip. engine—per ct. | 39.5 | 29.7 | 21 | 14 | 9.7 |
| | H.P. turbine—per ct. | ... | 8.9 | 20.6 | 24.5 | 30.5 |
| | L.P. turbine—per ct. | ... | 8.9 | 24 | 35 | 39 |

The E.H.P. developed on shaft was arrived at by deducting 10 per cent. from the H.P. recorded by the Watt indicator.

The estimated speed of 25 knots was obtained at the first trial, although the turbines were never working at the full effective pressure allowed for in the design, viz: 156 pounds. The curves of the slip of the screws show that at 21 knots speed the propeller surface is sufficient, but above this speed it is rather too small, and it was consequently decided to increase its surface by adding a second propeller to each of the shafts.

It is interesting to follow the variation in slip of the different screws as the power of the turbines is increased. With no steam in the turbines, and the vessel being propelled by the reciprocating engine alone at a speed of about 12 knots, the slip of the central propeller is about 40 per cent., while the water causes the wing propellers to turn the turbines at the rate of about 400 revolutions per minute. As the power of the turbines increases the slip of the middle screw is reduced to about 7 per cent., while the slip of the turbine propellers, on the contrary, beginning at zero, increases progressively to upwards of 30 per cent. for the high-pressure turbine and 39 per cent. for the low-pressure turbine propeller. The difference between these two figures arises from the fact that the low-pressure turbine gives notably more power than the high-pressure turbine, owing to its condenser being better than was expected.

Owing to the considerable reduction in the slip of the central propeller, as the wing propellers come more and more into play, the speed of rotation of the reciprocating engine does not increase in proportion to the speed of the vessel. By referring to the table, it will be seen that at the reduced speed of 12 knots the speed of rotation of the reciprocating engine is 369 revolutions, and at 25 knots (or double the first speed) only 516 revolutions per minute. On examining the curves of the turbines it will be seen that their speed of rotation rises from 393 to 1,455 revolutions for the high-pressure turbine, and from 395 to 1,657 for the low-pressure turbine, while the speed of rotation allowed for in the design was 1,500 to 1,600 revolutions per minute. As regards the steam consumption, with the combined system of engines, this is very moderate at a speed of 10 knots, and probably considerably less than when reciprocating engines, equal to the full power required, are worked at very low powers.

*Second Trials.*—A second series of trials was made on 19th January, 1904, after the propellers had been altered, the middle one being reduced to 3 feet 6 inches diameter, the pitch being kept up at 5 feet 6 inches. The high-pressure turbine was fitted with propellers of 2 feet 4 inches and 2 feet 8 inches diameter respectively, but both of the same pitch, while the low-pressure

turbine was fitted with propellers of 2 feet 4 inches and 2 feet 10 inches diameter, and 2 feet 6 inches and 2 feet 10 inches pitch respectively. The results obtained are summarized in Table D.

TABLE D.—MESSRS. YARROW & CO.'S TORPEDO BOAT. TRIALS OF 19TH JANUARY, 1904.

| Number of trial. | I. | II. | III. | IV. |
|---|---|---|---|---|
| Effective pressure of steam on admission to H.P. turbine—lbs. per square inch | 50 | 100 | 150 | 170 |
| Condenser vacuum—inches | 28 | 27.5 | 27 | 27 |
| Speed of vessel (two runs)—knots | 15.58 | 19.25 | 23.22 | 25.714 |
| | 20 | 23.53 | 26.67 | 27.067 |
| Mean speed of vessel—knots | 17.79 | 21.39 | 24.94 | 26.39 |
| Rotation of reciprocating engine—revs. per min. | 458 | 508 | 555 | 576 |
| H.P. turbine—revs. per minute | 836 | 1,052 | 1,207 | 1,258 |
| L.P. turbine—revs. per minute | 836 | 1,065 | 1,232 | 1,307 |
| Slip of propellers—Reciprocating engine—per ct. | 28.7 | 22.4 | 17 | 15.3 |
| Slip of propellers—H.P. turbine—per cent. | 13.6 | 17.4 | 16.4 | 14.8 |
| Slip of propellers—L.P. turbine—per cent. | 24 | 28.2 | 27.8 | 27.8 |

It will be seen that a speed of 26.39 knots has been obtained by giving the turbines rather more steam than they had been designed for. For the same steam pressure at admission, that is, for the same steam consumption, the speed is less than in the first trials, except at the maximum speed, when it is about the same. The slip of the screws is much reduced, as also the speed of rotation of the turbines. It may, therefore, be inferred that two screws give better results than the single screw originally employed; for, the speed of rotation of the turbines having been greatly reduced, their efficiency is much less. To increase this speed and obtain the estimated efficiency, the propeller surface must be reduced, and this was done for the third series of trials.

A point of interest is that the addition of a screw revolving in the neighborhood of the hull gave rise to considerable vibration, whereas, in the first trials the complete absence of vibration was specially noteworthy.

*Third Trials.*—A third set of trials was made on 4th March, 1904, with propellers all of the same pitch (2 feet 6 inches) and rather smaller diameter (2 feet 6 inches, 2 feet 4 inches, 2 feet 1 inch). The speeds obtained were approximately equal to those of

the second trials, for the same steam pressures in the high-pressure turbine, but the speeds of rotation of the turbines were increased by 16 per cent. The increase in the efficiency of the engines was therefore balanced by the reduction in the efficiency of the screws, the slip of which rose to 24.6 per cent. for those of the high-pressure turbine and 33.1 per cent. for those of the low-pressure turbine. It seems to be difficult to obtain more than this with propellers grouped in pairs on each shaft. This arrangement of two propellers, one in front of the other, is defective in so far that the second propeller works in water already disturbed by the first propeller. The highest efficiency is certainly obtained with a single propeller on each shaft, but in order that the slip should not exceed 25 per cent., which seems to be the maximum for a good duty, the propelling surface, and, consequently, the diameter, must be increased. This can easily be done when the shafts are nearly horizontal.

On Messrs. Yarrows' boat, the inclination of the shafts is rather steeper than it should be with propellers having a diameter greater than the pitch. Nevertheless, the speed of 26.4 knots, which has already been obtained, is no doubt capable of being improved upon, and the maximum obtained with reciprocating engines can, no doubt, be easily reached.

In conclusion, it will be seen from what has been said that steam turbines can be made practically equal to reciprocating engines for propelling ships at high speeds, but in order to obtain their full effect they must be mounted upon shafts very slightly inclined, and, if possible, with only one propeller on each shaft. The necessity for having horizontal shafts leads to a more sudden rise in the hull aft than is usual when reciprocating engines are installed. Hence, hulls constructed for reciprocating engines are not generally suitable for steam turbines.

It must not be concluded from the fact that, *cæteris paribus*, a higher speed is not obtained by merely substituting turbines for reciprocating engines, that the former are, therefore, inferior to the latter. A new form of propelling engine obviously calls for new lines of hull. At reduced speeds, the turbines are not economical, and they are inconvenient for going astern and for

maneuvering, but this drawback can quite well be remedied by combining turbines with a reciprocating engine, working a special shaft and mechanically independent of the turbines. Another arrangement, different from that in the Yarrow boat, whereby the reciprocating engine would supply about 40 per cent. of the total power, would give an increase of 15 to 20 per cent. of the power obtained with a reciprocating engine alone, besides having the general advantages characteristic of turbines.

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### THE PROGRESS OF THE SUBMARINE DURING 1903.

In a long letter to the "Times," London, April 5th, Mr. Alan H. Burgoyne, author of "Submarine Navigation; Past and Present," gives the following data:

With the presentation of the annual estimates, it is the custom of naval critics to compare the proposed number of battleships and cruisers with those projected by the other Great Powers; but the smaller craft are as a rule ignored—probably through lack of knowledge as to the real stage of construction reached in them by foreign navies.

Perhaps, therefore, the following résumé of the progress achieved in submarine vessels, since their general acknowledgement as effective units in future naval warfare, may not be without interest. Taking our neighbor France first, we find that there are twenty-six, of various types, complete; these have been distributed as follows:

Cherbourg.—*Narval*, *Sirène*, *Triton*, *Silure*, *Espadon* (submersibles), and *Morse*, *Français*, *Algérian*, *Naïade*, *Protée*, *Lynx*, *Ludion* (submarines).

Rochefort.—*Gnôme*, *Lutin*, *Loutre*, *Castor* (submarines).

Toulon.—*Gustave*, *Zédé*, *Gymnôte*, *Perle*, *Esturgeon*, *Bonite*, *Thon*, *Souffler*, *Dorade* (submarines).

Bizerta.—*Farfadet*, *Korrigan* (submarines).

Under construction there are ten submersibles and eleven submarines, bringing the total up to forty-seven. The following are the chief features of the French under-water craft:

| Type. | No. | Displacement. | Length. | Beam. | Draught. | Speed. | | Torpedo armament. | Complement. | Designer. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Surface. | Submerged. | | | |
| | | *t.* | *ft.* | *ft. in.* | *ft. in* | *kts.* | *kts.* | | | |
| *Gymnôte* (1888)..... | 1 | 30 | 58½ | 6 | 6 | 8 | 6 | 2 14-D.C. | 4 | Gustave Zédé. |
| *Gustave Zédé* (1893). | 1 | 266 | 159 | 12½ | 12½ | 10 | 5 | 1 bow tube. | 9 | Romazzoti. |
| *Morse* (1889)..... | 1 | 144 | 118 | 9 | 9 | 12.3 | 6 | 1 bow tube. | 9 | Romazzoti. |
| *Narval* (1889)..... | 1 | 106 / 200 | 111½ | 12½ | 5½ | 11.3 | 8 | 4 18-in. D.C. | 9 | Laubeuf. |
| *Sirène* (1901)..... | 4 | 146 | 118 | 9 | 9 | 13 | 8 | 4 D.C. | 9 | Romazzoti. |
| *Français* (1901)..... | 2 | 187 | 135½ | 9½ | 9½ | 12½ | 8 | 4 D.C. | 9 | Maugas. |
| *Farfadet* (1901-2)..... | 4 | 68.025 | 77 | 7½ | 8 | 8 | 6 | 4 D.C. | 5 | Romazzoti. |
| *Naïade* (1901-3)..... | 20 | 168 | 122½ | 10½ | 7½ | 10½ | ... | ..... | ... | Romazzoti. |
| "*X*" (1903)..... | 1 | 213 | 142½ | 9 10 | 9 10 | 11 | ... | ..... | ... | Bertin. |
| "*Y*" (1904)..... | 1 | 202 | 153½ | 9 10 | 9 10 | 11 | ... | ..... | ... | Maugas. |
| "*Z*" (1904)..... | 1 | 301 | 160½ | 13½ | 9 | 11 | 8 | 2 tubes, 2 D.C. | 20 | Bertin. |
| *Omega* (1904).. ..... | 1 | 430 | ... | ... | ... | 15 | ... | ..... | ... | Maugas. |
| *Aigrette* (1904)..... | 2 | 172 | 117½ | 12½ | 8½ | 10½ | 7 | 4 D.C. | 20 | Laubeuf. |
| *Q 41* to *Q 46* (1905)... | 6 | Particulars unknown. | | | | ... | ... | ..... | ... | ..... |
| *Q 47* (1905)..... | 1 | | | | | ... | ... | ..... | ... | ..... |
| *Q 48* to *Q 58* (Projected)... | ... | ... | ... | ... | ... | ... | ... | ..... | ... | ..... |

NOTE.—D. C.=Drop collars, for carrying torpedoes, externally.

It will be seen that France's submarines form a very formidable fleet indeed, and I can vouch for the efficiency of her latest types. The vessels of the *Naïade* class are, perhaps, the finest weapons of harbor defense as yet evolved. Four of these will this year be transported to the East, two for the defense of Tonkin and two for Saigon. *X* is one of the few twin-screw submarines in existence. The six just laid down at Toulon and Cherbourg, from the designs of Engineer Maugas, will be the largest, speediest and best armed submarine vessels in the world.

Turning to Russia, we find this Power has eight complete and six under construction. There have been many rumors and fallacious reports concerning the number and type of these vessels, and it will therefore be of particular interest to know definitely such details as have been allowed to escape the vigilance of the censor. The most important is a submersible boat designed by Engineer Bubnoff. Her dimensions are as follows: Displacement (surface), 175 tons; length, 77 feet 1 inch; diameter, 14 feet; I.H.P., 200 = ten knots on the surface. The motive power consists of a petroleum engine for the surface and electric motors (giving eight knots) for submerged work. The armament comprises four Drzewiecki drop-collars (D. C.) for 18-inch torpedoes. She was launched in 1903. The next two are submersibles from

designs by Engineer Drzewiecki, and have a length of 80 feet and diameter of 14 feet. The surface speed is 12 knots; one of these is completing in the Black Sea. The fourth and fifth are from plans by Lieutenant Engineers Kuteinikoff and Kolbasieff; the smaller, the *Petr Kochka*, has dimensions as follows: Displacement, 20 tons; length, 50 feet; beam, 14 feet; depth, 10 feet; speed, with twin screws, 8 knots on the surface and 6 knots submerged. The motive power is electricity stored in accumulators of the Pari type. Armament, two torpedo tubes; cost, 50,000 roubles. I can obtain no details concerning the second of these craft, and it is even doubtful if it has yet been laid down.

The *Petr Kochka* was taken by train to Sevastopol to be shipped thence to Port Arthur. Whether it arrived before the outbreak of hostilities or not it is impossible to say. The sixth Russian submarine was launched in 1900. It was constructed to designs by Engineer Pukaloff, and, with electricity as motive power, has submerged and surface speeds of 7 knots and 10 knots respectively.

The remaining two are submersible torpedo boats, capable of sinking to the level of the deck, but not intended for total submergence.

Germany has five submarines finished and one building. Two more are to be laid down shortly, if not already commenced. The completed ones include three Nordenfelts, a Holland and an experimental vessel launched from Howaldts, Kiel, in 1901. The one building is a modified Holland from German Government designs. The two proposed are large submersibles, also from Government plans.

Italy has five submarines afloat or under construction, and four more will be commenced immediately. The *Delfino*, designed by Engineer Pullino, is undergoing modification, her speed being insufficient; after reconstruction her dimensions will be: Displacement, surface, 104 tons, submerged, 111 tons; length, 78 feet 6 inches; diameter, 10 feet 1 inch; I.H.P., 150 = 12 knots light (*i. e.*, 95 tons displacement) and ten knots awash; armament, two torpedo tubes. The *Glauco*, completing at Ven-

ice and designed by Engineer Caesar Laurenti, is, in my humble opinion, the most advanced of all those yet laid down. In form she resembles an ordinary torpedo boat, and the speed is to be not less than 14 knots, and this, the inventor assures me, will be easily obtained. Her radius of action will be 2,000 miles. The *Tritone*, launched at Spezzia, is a small electrically-driven (8.5 knots surface) submarine. Engineer Ruffini is responsible for the design of the remaining two. Four submersibles of the *Glauco* type are to be built this year.

America has eight submarines of the Holland type afloat and four sub-surface torpedo boats (designer, Clarence P. Burger) on the stocks. The *Protector*, built as a speculation by the Simon Lake Syndicate, will probably be added to the fleet. The position of its submergence planes constitutes the weak point of this design. An experimental "one man" boat, invented by Mr. Moriarty, is also under construction. The *Fulton*, the property of the Holland Torpedo Boat Company, may possibly be bought by the Government.

This résumé has already assumed far greater proportions than I originally intended, and I will cut it short by giving the remaining submarines of the world (as also our own and those already enumerated) in tabulated form:

| | Afloat. | Building. | Proposed. | Total. | Notes. |
|---|---|---|---|---|---|
| England.... | 9 | 10 | 10 | 29 | |
| France ..... | 26 | 21 | 11 | 58 | |
| Russia..... | 8 | 6 | 20 | 34 | |
| Germany... | 5 | 1 | 2 | 8 | |
| Italy ..... | 3 | 2 | 4 | 9 | |
| U. S. A..... | 10 | 5 | 2 | 17 | Including *Protector* and *Fulton*. |
| Sweden..... | 2 | ... | 4 | 6 | |
| Spain..... | 2 | ... | 20 | 22 | |
| Brazil ..... | 3 | 1 | ... | 4 | Two of them small Goubets. |
| Portugal.... | 1 | 1 | ... | 2 | The *Plongeur* was launched in 1892. |
| Turkey..... | 2 | ... | ... | 2 | Old Nordenfelts. |

Besides these, Austria, Holland, Argentine and Norway have all shown interest in the subject, each making exhaustive trials

with experimental boats. Austria has the *Hoffman*, Holland a *Holland*, and Argentine the *Recaldoni*. Norway has not gone further than proposing to buy a *Holland*.

Of our own submarines I will say little; the first batch of five were essentially for experimental and training purposes. *A1* was a bad diver and insufficiently armed; also she had a conning tower that might be improved upon with advantage. Her sisters, *A2*, *A3*, *A4*, have been given an extra torpedo tube, and, moreover, are far better divers. The blunt semi-spherical bow of the first 63-foot 4-inch lot has been modified for the better, the speed and seaworthiness improving as a consequence. I still hold that the speed and displacement of our vessels are inadequate, but these deficiencies are to be remedied in the new class. Also it seems to me obvious that ten is scarcely a reply to the programme of our Continental friends; we have passed the days of mere experiment, and the recent success of the torpedo as a weapon in the Far East should impress on one and all the immense value of the least visible and therefore most indispensable torpedo boat in the world—the submarine.

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SEA SCOUTING.

The following is from an "Engineering" editorial under date of April 22, 1904.

The launch of the first scout specially built for such duty is an event of the first importance, especially as it seems doubtful if we have always fully realized the importance of this requisite to successful strategy, notwithstanding that in practically every naval war the need for very extensive reconnoissance has been clearly demonstrated.

The success of the torpedo-boat destroyer for scouting duty has been established, but for sea scouting something more powerful than the destroyer is obviously required. Such a vessel must not only be structurally strong to keep the sea, but must have a large radius of action. Doubt was cast on the strength of destroyers by the loss of the *Cobra*, but very exhaustive in-

quiry by naval architects of high repute has established the fact that those vessels are quite capable of the service for which they were designed. An attempt was made in the last vessels ordered to strengthen the hull at the cost of speed—25½ knots being the maximum, as compared with 30 knots; but in the newer vessels 27 knots will again be aimed at, which is necessary if these vessels are to be effective against the light torpedo boats of foreign nations.

Even the best of destroyers will not be able to go to sea under all weather conditions, and in even moderate storms will not be able to exceed 20 knots. But the boats which they have been designed to meet and defeat will fall still further short of this The radius of action of destroyers is small; their total bunker capacity for 70 tons might enable them to steam for 2,000 to 2,500 miles at low speed, but would only be sufficient at 26 or 27 knots to carry them over a distance of 300 to 400 miles.

In the past, sea reconnoissance work has been carried out by ordinary cruisers, and there can be no doubt that the ideal condition calls for the most powerful cruiser afloat; because it is not sufficient for the Admiral to know that part of the enemy's squadron is in a given position; it is of the highest importance that he should know where lurks the whole strength of the enemy's fleet. A knowledge of the conditions over a wide radius is necessary; and following this a reconnoissance in force is desirable, so that there may be power to penetrate the enemy's screen, in order that the full strength of the opposing fleet may be ascertained; and this, as a rule, involves some form of isolated action. Reconnoissance work should be carried out by all-powerful cruisers. That is the ideal; but, unfortunately, there are financial limitations, so that it is impracticable to have a sufficient number of well-armed cruisers to scour a wide enough area to make the reconnoissance truly effective, and it became a question of creating special ships whose speed and sea-keeping qualities would enable them to discover the enemy's fleet, and bring such information to the Admiral as would enable him either to verify the information by sending out sufficiently pow-

erful cruisers as a reconnoissance in force, or to prepare for a fleet action.

There is also the very important question of speed. The scouting ship ought always to have a considerable superiority in speed over the vessels in the opposing fleet. Except our destroyers, British ships intended for reconnoissance work are of less speed than our modern armored cruisers, and are little more than equal in sea speed to the possible performances of our later battleships. The importance of high-speed scouting ships is clearly shown when we note the higher speeds of large modern warships. Sixteen years ago we were only building battleships of 17 knots. Today we have thirty-one vessels of the first line whose speed exceeds 18 knots; France has fourteen, Russia ten, Germany fifteen and Japan six. The speed of armored cruisers in the 'eighties was only 18 knots, whereas today we have twenty-six vessels which are of 23 knots speed; France has five exceeding 22 knots, and Japan two; but in the case of Russia and Germany 21 knots is the highest reached. It was, perhaps, quite sufficient, therefore, that the speed of our fastest second-class or torpedo cruisers sixteen years ago should be from 17 to 18 knots, as that practically equalled the performance of the larger ships; but today a different condition is called for. It is a striking fact that Russia has recognized the importance of scouting to a fuller extent than any other naval power, as for this duty she has fifteen cruisers and gunboats whose speed exceeds 22 knots, several of of them being able to steam at 25 knots. Germany has seven such vessels exceeding 22 knots; France has five, and Japan four; while the only unarmored British ships which exced 21 knots are eight scouts now being built.

The progress in professional opinion in regard to these scouts has been very considerable. When Admiral Fitzgerald read his paper before the Institution of Naval Architects suggesting such a vessel, the idea did not seem to be quite welcome. Admiral May questioned whether the expenditure involved would be commensurate with the service rendered in view of the deficiency in gunpower, and of the impossibility of the vessel penetrating sufficiently far into the enemy's position to ascertain accurately

the extent of the fleet. Today there is a wide concensus of opinion that these vessels, owing to their high speed, wide radius of action, and sea-keeping quality, may be able to bring to the Admiral information of the highest importance. These vessels have been designed by the respective builders, the Admiralty having invited designs along with the tenders; and it is a notable fact that while the aim at first was to get the lightest possible vessel to perform the duties, the negotiations resulted in all the ships being brought to about the maximum displacement suggested.

Four ships were ordered under the programme of 1902–3 and four under the programme of 1904–5. Two are being built by the Vickers Company; two by Sir W. G. Armstrong, Whitworth and Co.; two by the Fairfield Company; and two by Cammell, Laird and Co., of Birkenhead. A description of the first of the ships launched—the *Sentinel*, by the Vickers Company—is published on another page of this issue. Their ship is the shortest of the four designs, being 360 feet, while Armstrong's is 374 feet; Laird's, 370 feet; and the Fairfield Company's is 365 feet. But the Barrow ship has the most beam, the ratio of length to breadth being 9 to 1, whereas in the other ships it ranges between 9.4 to 1 and 9.55 to 1. The Vickers ship, too, has the greatest displacement—2,920 tons; while the others are from 2,850 to 2,800 tons. The speed of 25 knots, in connection with the Vickers ship, is expected to be realized with a horsepower of 17,000, which is equal to 5.87 indicated horsepower per ton of displacement; while in the other boats the engines are to be of 16,000 or 16,500 horsepower.

Under normal conditions the vessels will carry 150 tons of coal, but they will have capacity for carrying 370 tons altogether. This latter, it is anticipated, will give them a radius of action of 700 miles at full speed, 1,250 miles at 20 knots, of 2,500 miles at 15 knots, and of 5,200 miles at 10 knots; so that even when they have steamed far with the fleet they will be able to act as "scouts" for long distances at full speed without having to recoal. As to gun power, they are undoubtedly designed on the principle of running away from anything heavier than a torpedo

destroyer, because they are fitted only with ten quick-firing guns firing 12-pound shot, in addition to eight guns using 3-pound shot. This armament would be effective against torpedo-boat destroyers, which, as a rule, are only equipped with one 12-pounder and five 6-pounders.

As the Russian cruiser *Novik* is in some respects an equivalent of these scouts, it may be noted that she has a displacement of 3,200 tons, with dimensions not differing materially from those of the British ships, and a speed of 25 knots is realized with 18,000 indicated horsepower. Her full coal supply is 600 tons, and the gun power materially greater than that of the British ships; in her case there are six 4.7-inch guns firing 45-pound projectiles, eight 1.8-inch guns, two 1.4-inch guns, and three Maxims. This armament, it will be seen, is more effective than in the British scouts, but as it cannot enable the ship to face anything in excess of a gunboat or destroyer, it is doubtful if the extra weight involved is justified by the result. The 4.7-inch guns may be said to be unnecessarily powerful for use against destroyers, and are not sufficiently effective against larger craft, excepting opposing scouts. When Admiral Fitzgerald proposed his ship he suggested a displacement of 3,800 tons, with six 4-inch guns and a dozen machine guns; but Mr. Philip Watts, the present Director of Naval Construction, considered that there ought to be eight 6-inch quick-firers, instead of six 4-inch guns. The heavier guns would have been an advantage, especially against opposing scouts; but whether they would have enabled the vessel to stand up against even a second-class cruiser under the conditions prevailing to-day, when the 6-inch gun is giving place to the 7.5-inch gun so exclusively, is doubtful. Moreover, the question of cost comes in. Mr. Watts stated that a ship with such an armament as he had in his mind would cost about £310,000; but the smaller and less powerfully-armored scouts now being built for the British Navy are involving an average expenditure of £280,000; so that the additions he proposed would have involved something nearer £400,000 than the sum he mentioned, and there are many who might consider such an expenditure for a vessel for scouting duty excessive. On the other hand, it must be accepted that

the money spent on scouting duty is the most profitable payment that can be made on behalf of a fleet. Accurate information placed in the possession of the admiral at the earliest possible moment is vital to the success of any action; it constitutes the difference between possible success and probable failure. Scout money must be recognized as insurance against failure in war, just as the cost of the maintenance of our powerful fleet represents the premium to maintain peace.

# SHIPS.

## UNITED STATES.

**Virginia.**—As noted in our last issue, the battleship *Virginia* was launched at the yards of the Newport News Shipbuilding & Drydock Co., Newport News, Va., at 1 P. M., April 5th. The whole ceremony was promptly executed and with nothing whatever to mar its complete success.

The *Virginia* is one of the three battleships authorized in March, 1899, and, together with two others authorized in June, 1900, forms a class having like characteristics. The others, not yet launched, are the *Nebraska*, *Georgia* and *New Jersey*, the *Rhode Island* having been launched just six weeks later than the *Virginia*.

The general dimensions and characteristics of this type are: Length on load water line, 435 feet; beam, extreme, 76 feet 2½ inches; draught, on normal displacement of 14,987 tons, 23 feet 9 inches; draught, greatest, full load, about 26 feet; designed indicated horsepower, 19,000; speed, 19 knots; complement of officers, 40; complement of seamen, marines, etc., 772.

In the 15,000 tons displacement of these vessels, the many qualities essential to a perfect fighting machine have been compromised and combined in the proportion which experience seems to have pointed out as the most desirable and efficient. These battleships have a speed of 19 knots, which compares favorably with any battleships abroad, either under construction or projected.

*Propelling Machinery.*—There will be two sets of vertical, inverted, triple-expansion, direct-acting, propelling engines, designed for 19,000 collective horsepower at 120 revolutions per minute. Each engine will be placed in a separate watertight compartment, and will have cylinders 35 inches, 57 inches and two 66 inches diameter, by 48 inches stroke of piston.

Steam at 250 pounds pressure will be supplied from twenty-four water-tube boilers of the Niclausse marine type. The boilers will be arranged in six watertight compartments. The total grate surface of the twenty-four boilers will be 1,460 square feet, and the total heating surface will be 57,534 square feet. The smoke pipes will be three in number, standing fore-and-aft.

*Battery.*—The main battery will consist of four 12-inch breech-loading rifles, mounted two in each superposed turret on the center line of the vessel; eight 8-inch breech-loading rifles, mounted two in each superposed turret and two in each side turret; and twelve 6-inch rapid-fire guns. There will be a secondary battery of twelve 3-inch and twelve 3-pounder guns, besides four 1-pounder automatic guns, four 1-pounder rapid-fire guns, six Colt automatic guns, two machine guns and two 3-inch field guns.

There will also be two submerged torpedo tubes.

*Armor.*—An armor belt will extend five feet below and three feet above normal load line from stem to stern. It will be 11 inches thick at the top and 8 inches thick at the bottom. The maximum thickness will be preserved for a depth of five feet from the top. The armor will taper at the stem and stern to a thickness of 4 inches. The armor on the superposed balanced oval turrets, with inclined port plates, will be 12 inches thick on the port plate, 8 inches thick on the sides and 6 inches thick on the rear.

The applications of electricity on board are much more general than in the case of any other battleships in existence, with the possible exception of the *Kearsarge* and the *Kentucky*. All the turrets have electrical turning gear, and the ammunition hoists, blowers for turret and for general ventilation, the general workshop, winches, boat cranes, and practically all auxiliaries outside of the engineers' department excepting capstan and steering gear, are to be electrically driven. To provide for the power required for these purposes, there will be installed eight engines and dynamos, mounted on combination bedplates, two having a rated output of 1,250 ampères at 125 volts and six with 625 ampères at 125 volts.

The designs of hull, machinery, armament and equipment embody the latest and best features of naval progress, and this class will be a powerful factor in the fighting strength of the Navy.

**Rhode Island.**—This battleship, one of the class just described under the *Virginia*, was successfully launched from the yard of the Fore River Ship and Engine Company, Quincy, Mass., at 12·30 P. M., May 17th. These two vessels are practically counterparts in all principal features except boilering, in which they differ in the system installed. In the *Rhode Island* there are to be Babcock & Wilcox boilers having a total grate surface of 1,342 square feet and total heating surface of 56,184 square feet.

**California.**—The armored cruiser *California* was successfully launched from the yard of the Union Iron Works, San Francisco, California, April 28, 10·40 A. M.

The *California* exceeds the average battleship in dimensions, and has an armament but slightly inferior, while in point of speed she outclasses the battleship type. The *California* is one of the six armored cruisers of this type, the others being the *Pennsylvania*, *West Virginia*, *Colorado*, *Maryland* and *South Dakota*, which, when in service, will test the relative efficiency of the cruiser and the battleship.

This vessel has a length between perpendiculars of 502 feet, an extreme breadth of 69 feet 6½ inches, a mean draught of 24 feet 1 inch, and a displacement of 13,800 tons. She is fitted with twin screws, vertical, triple-expansion, four-cylinder engines and Babcock & Wilcox water-tube boilers, designed to develop an indicated horsepower of about 23,000 for a speed of 22 knots. The full bunker capacity is 2,000 tons; normal coal supply, 900 tons.

The main battery consists of four 8-inch breech loading rifles, 45 calibers, in two balanced turrets, and fourteen 6-inch rapid-firing guns, 50 calibers, on the broadside. The secondary battery consists of eighteen 3-inch rapid-firing guns, 50 calibers, twelve 3-pounder rapid-firing guns, eight 1-pounder rapid-firing guns, two 3-inch rapid-firing field guns and six automatic guns.

The vessel is also fitted with two 18-inch Elswick submerged torpedo tubes forward. Side protection to consist of a 6-inch belt at the water line and 5-inch armor on the top sides. The turret armor is from 6 inches to 6½ inches thick, the barbette armor is also 6 inches thick. The protective deck is 4 inches thick on the slope and 1½ inches on the flat. The complement consists of a crew of 690 men, with accommodations provided for 37 additional for a flagship and a marine guard of 60, making a total complement of 787.

The contract was signed January 10, 1901, but the keel was not laid till May 2, 1902. The contract price of the hull and machinery is $3,800,000.

The vessel was launched on convex curved ways with a camber of one in 300, the length of the ground ways from the forward poppet to the after end was 508 feet, the length of the cradle was 369 feet, the collective width of the ground ways on the one side was 36 inches, the distance between centers of ground ways was 20 feet, the mean inclination of the ways at the center of the cradle at the start was one to 27½, the launching weight of the vessel, including cradle, was 5,980 tons.

AUSTRO-HUNGARY.

**Erzherzog Friedrich.**—The Austrian battleship *Erzherzog Friedrich*, which was launched at Trieste on April 30, has a length of 387 feet; beam, 71.23 feet; draught, 24.54 feet; displacement, 10,600 tons; engines, 14,000 horsepower; speed, 19.25 knots. Her armor belt will extend 9 inches above and 3 feet 11.24 inches below the water line. The whole of her armor will be of Witkowitz nickel-steel, and will weigh 2,922 tons. Her auxiliary engines will number 87, with 140 steam cylinders. She will carry four 9.45-inch, twelve 7.48-inch, fourteen 2.75-inch, and ten 1.45-inch guns, four mitrailleuses, and two submerged torpedo tubes of 17.71-inch caliber. Her 7.48-inch guns will each fire four rounds a minute.

ENGLAND.

**Argyll.**—The first-class armored cruiser *Argyll* was launched March 3. The principal dimensions being the same as of her

predecessors of the same class, these need only be briefly recapitulated, although in general construction the new vessel will have features peculiar to herself which demand fuller notice. The principal dimensions are:—Length, between perpendiculars, 450 feet; beam, 68 feet 6 inches; depth, molded, 38 feet 6 inches; mean draught, 24 feet 9 inches; displacement, 10,700 tons; I.H.P., 22,000; speed, 22½ knots. Owing to the fact that the launch was delayed for some months pending the completion of the new dock and crane, the hull of the *Argyll* is in an unusually forward state of construction, and the launching weight was greater than that of any of the other cruisers of the class when put into the water. More than the usual amount of machinery had also been put on board prior to launching.

The vessel has an armored side between the main and lower decks about 13 feet wide, and extending for 250 feet fore and aft, of 6-inch specially hardened steel. This protects the vital parts of the ship, and encloses the engines and boilers, magazines and shell rooms, workshops, and stores. Forward of the 6-inch belt a 4½-inch belt extends to near the bow, where it is tapered to 2 inches, and runs into the ram, thus stiffening this important part of the structure. The armor is bedded on teak planking, behind which are two thicknesses of ordinary steel plating. A citadel armored bulkhead, 4½ inches thick, runs across the vessel at the after end of the 6-inch belt, thus enclosing all the important parts. Abaft this the protective deck of 2 inches thick protects the after part of the ship including the steering gear. The main deck over the armor is built of two thicknesses of steel plate, as is also the lower deck, which is of the turtle-back form. The hull is subdivided into over 200 watertight compartments, fitted with watertight doors and scuttles. The double bottom extends all through the engine and boiler space and under the magazines forward and aft, part of it being fitted for carrying reserve feed water for the boilers. The coal bunkers, extending all along the engine and boiler spaces, afford additional protection behind the armor, and have a capacity of over 1,800 tons.

Beginning with the *Argyll* the Admiralty has recently decided to strengthen the fighting power of the forward battery in vessels

of her class, and render them still more formidable war vessels. Instead of the 6-inch guns in the forward casemates, there will be 7.5-inch Q.F. guns in barbettes on each side. This will necessitate alterations in the forward part of the ship. The top sides will have to be cut back and the casemates removed to give the necessary clearance for the larger guns. Magazines and shell rooms below will be modified to suit the new armament. The armament will now consist of four 7.5-inch Q.F. guns in barbettes, six 6-inch Q.F. guns in casemates, two 12-pounder Q.F. guns, twenty-three 3-pounder Q.F. guns, two Maxim guns, and two 18-inch submerged torpedo tubes. The barbettes and casemates are of specially hardened steel 6 inches thick. The 7.5-inch guns are in direct communication with their own magazines and shell rooms, there being a central armored hoist from each barbette worked by hydraulic power, thus enabling the men working the guns and those supplying the ammunition and shell to be always under protection. There is also an ammunition passage running along each side of the engine and boiler space under the the lower protective deck, connecting the fore and after ends of the vessel, so that, should either the forward or after guns be put out of action, the ammunition can be transported to either end as required.

The propelling machinery of the *Argyll* which is being supplied by the builders, consists of two sets of triple-expansion engines, arranged in separate water-tight compartments. Each set has four cylinders, the diameter being: high-pressure, 41½ inches; intermediate-pressure, 65½ inches; and two low-pressure, each 73½ inches, all having a stroke of 3 feet 6 inches. The engines will develop 21,000 indicated horsepower. The high-pressure and intermediate-pressure cylinders are fitted with solid forged-steel liners, the intermediate pressure cylinders being steam-jacketed. The shafting is hollow, the crank shaft being 18 inches exterior and 9 inches interior diameter. There are four large condensers, which serve for the main and auxiliary engines. The total cooling surface is 26,300 square feet, and the condensers are arranged so that any one may be overhauled while the others are at work.

There are four separate boiler rooms. In the after boiler room six single-ended cylindrical boilers are fitted. In the other three boiler rooms sixteen water-tube boilers of the Babcock & Wilcox type are fitted; all the boilers are arranged to work under a modified system of forced draft and yield a pressure of 220 pounds. Fourteen fans are fitted in the boiler rooms, driven by enclosed steam engines, and six electrically-driven fans in the engine rooms for ventilating purposes.

**Devonshire.**—First-class armored cruiser. Launched at Chatham, April 30th. Principal dimensions, armor and armament the same as the *Argyll*, just described. The propelling machinery will be similar also, except that the *Devonshire* is to have twenty-two Niclausse boilers instead of the sixteen Babcock & Wilcox boilers of the *Argyll*.

The first keel-plate of the *Devonshire* was laid by the Prince of Wales on March 25, 1902, but the construction of the vessel was delayed, as alterations in the design were considered necessary. By the time the vessel is ready to leave the slipway she will be in a very advanced stage, and she will be almost completed during the ensuing financial year.

**New Zealand.**—Launched from the Portsmouth dockyard February 4th. The battleship *New Zealand* is one of the *King Edward* class, 454 feet long, displacement 16,350 tons. Her armament consists of eighteen heavy guns in barbettes and armored batteries on the upper and main decks, and thirty smaller quick-firing guns and Maxims, besides four submerged torpedo tubes. She will be fitted with three cylindrical boilers and eighteen water-tube boilers of the Niclausse type, capable of developing 18,000 horsepower and an estimated speed of 18½ knots.

**Swiftsure.**—On April 8th this battleship, built by Sir W. G. Armstrong, Whitworth & Co., carried out successful speed, gunnery and torpedo trials in the presence of a large staff of Admiralty officials and representatives of the fleet reserve, including Captain White, superintendent of contract work for the Tyne and Thames district. After leaving dock at Chatham, 1,000 tons of coal were put on board the vessel, and water ballast was

added until the draught of the vessel reached 24.10 feet, or 4 inches in excess of her normal draught. The thirty-hours' duration trial began on the 25th ult., and throughout this trial the engines, by Humphreys, Tennant & Co., ran at 130 revolutions and developed a power of 8,700 horses, or just over three-fifths of the contract power. During the trial a considerable sea was running, with a fresh easterly breeze. Four runs were made on the measured mile off the mouth of the Tyne before the conclusion of the trial, and these runs gave a speed of over 17.5 knots, the revolutions being slightly above 130, and the H.P. 8,670. The air pressure in the stokeholds during the 30 hours was *nil*. The ship was anchored off the Tyne until the morning of the 29th ult., additional water ballast having been taken on board during the interval. The six-hours' full speed trial was then begun, with the vessel at a draught of 24 feet 7½ inches.

During the six-hours' trial six consecutive runs with and against the tide were made over the measured course. The mean speed of these runs worked out at 20.05 knots with 151 revolutions; indicated horsepower, 13,470. The mean horsepower during the whole of the six hours worked out at 14,018, so that the speed obtained on the six runs would be more than maintained throughout the rest of the trials. The gunnery and torpedo trials were proceeded with on the 30th, and, owing to the fine weather which prevailed, these trials, although so extensive, were completed in a day. The guns passed through the usual service trial, and one of the 7.5-inch guns and two of the 10-inch guns were also selected for rapid firing at a target. During these trials for rapidity the ammunition was served exactly as it would be served in action, and everything was carried out under the same conditions. The guns were worked by men from the Elswick works, but a trained captain of the turret was lent from the *Excellent* to do the actual shooting. The accuracy of the shooting and the rapidity of the firing were entirely satisfactory. Although several rounds from the 10-inch guns were fired right over the decks fore and aft, no damage was done to the structure or fittings of the vessel in spite of this severe test.—"Steamship."

**The Engines of the Armored Cruisers Kent, Lancaster**

**and Cornwall.**—H. M. S. *Kent* was built at Portsmouth and H. M. S. *Cornwall* at Pembroke, while H. M. S. *Lancaster* was built by Sir W. G. Armstrong, Whitworth & Co., at Elswick Shipyard, the machinery in all three cases being supplied by R. & W. Hawthorn, Leslie & Co., St. Peter's Works, Newcastle-on-Tyne.

The main propelling machinery consists of two sets of triple-expansion four-cylinder vertical engines, working at a steam pressure of 250 pounds per square inch. The diameter of the high-pressure cylinders is 37 inches, that of the intermediate 60 inches, and that of each of the low-pressures 69 inches, the stroke being 42 inches. The engines run at about 145 revolutions per minute when developing 22,000 indicated horsepower.

The engines are balanced on the Yarrow, Schlick and Tweedy system, the high and intermediate cylinders being in the center, and the two low-pressure cylinders at the ends. The high and intermediate cylinders are each fitted with piston valves, the low-pressure valves being treble-ported slide valves. The main crank shafts, which are hollow, are made in two pieces for each engine —*i. e.*, with two crank throws on each piece. This enables the centers of the two adjacent cylinders to be brought as close as possible. The main bedplate frames are steel casings, and each cylinder is supported by a back column of cast iron of Y shape and two forged-steel front columns. The main condensers are four in number, having a total cooling surface of 23,000 square feet; they are arranged two in each engine room, and are fitted with suitable shut-off valves, so that either condenser can take the steam from both low-pressure cylinders should it be necessary to shut off one condenser for repairs. The vessels are fitted with all the auxiliaries customary for machinery of this class.

While the engines are alike in all three ships, the *Kent* and *Lancaster* are fitted with Belleville boilers, whereas the *Cornwall* is fitted with Babcock & Wilcox boilers.

In the case of the two former vessels the boiler installation consists of thirty-one Belleville boilers fitted with economizers. The total heating surface is 50,300 square feet, and the total grate

area is 1,610 square feet. The boiler installation of the *Cornwall* consists of twenty-four Babcock & Wilcox boilers, these having a total heating surface of 56,604 square feet and a total grate area of 1,623 square feet.

The steam trials of all three vessels proved very satisfactory, those of the *Kent* and *Lancaster* having taken place a few months ago. The following are the results obtained from the trials of the *Cornwall:*

| | 30-hours' trial at 4,500 I.H.P. | 30-hours' trial at 16,000 I.H.P. | 8-hours' trial at 22,000 I.H.P. |
|---|---|---|---|
| Steam pressure on boilers | 215 | 225 | 242 |
| Mean air pressure | Nil | .1 | .59 |
| Revolutions, starboard | 92.3 | 135.7 | 148.7 |
| port | 91.8 | 134.3 | 147.2 |
| Indicated horsepower, starboard | 2,380 | 8,161 | 11,284 |
| port | 2,420 | 8,326 | 11,415 |
| Total indicated horsepower | 4,800 | 16,487 | 22,699 |
| Mean speed in knots | 15.3 | 21.835 | 23.689 |
| Coal per indicated horsepower per hour, lbs. | 1.73 | 1.69 | 1.94 |
| Water per indicated horsepower per hour for both main and auxiliary engines, lbs. | 17.9 | 17.45 | 17.9 |

It will be remembered that the earlier vessels of the *County* class did not realize the anticipated speed of 23 knots, and it was found necessary to introduce certain modifications in the propellers, with a view to improving the speed performance of the ships. With the propellers as originally fitted, the best speed obtained with the *Kent* was 22.6 knots, whereas with the altered propellers the *Lancaster* obtained the high speed of 24.01 knots as a mean of two long-distance runs; while the *Cornwall* obtained a speed of 23.689 knots as a mean of eight hours' steaming. The speed obtained by the *Lancaster* is believed to be the highest speed obtained in point-to-point steaming by any vessel of the class, but was borne out by the *Cornwall*, which on one pair of runs also gave a speed of practically 24 knots. We may mention that at one part of the trial the machinery of the *Cornwall* was developing upwards of 24,000 horsepower without any excessive forcing of the boilers, and this power could certainly

have been maintained for a considerable period if necessary.—"Engineering."

**Sentinel.**—There was launched April 19th, from the works, at Barrow-in-Furness, of Vickers, Sons and Maxim, the *Sentinel*, the first of the new scouts to be floated. The vessel is 360 feet between perpendiculars, has a breadth of 40 feet, and at her load draught of 14 feet 2 inches has a displacement of 2,920 tons. She has a foremast for signaling purposes, fitted with a signal yard and gaff, and a gaff for wireless telegraphy, as well as a truck semaphore. Her armament consists of ten 12-pounder guns, eight 3-pounder guns and two 18-inch deck torpedo tubes. The machinery, magazines and steering gear are protected by a steel deck in the neighborhood of the water line, which extends for the full length of the vessel, the sloping side being 1½ inches thick and the flat portion of the deck ⅝ inch thick. The conning tower is of Krupp non-cemented armor, 3 inches thick. She has a sea speed of 25 knots, and a coal endurance of 4,000 knots at cruising speed. The officers are berthed aft and the crew forward and amidships. She is fitted with bath rooms and wash places for the captain, officers, petty officers, engine-room artificers, stokers and seamen. She is provided with electric lighting throughout, including two powerful searchlights. The ship is well ventilated by natural means, and in addition below the upper deck, by powerful electric fans. She has a complement of ten boats of various sizes, including a 32-foot steam launch. A feature of the vessel is an ammunition passage under the upper deck, which gives the crew transporting the ammunition from the magazines to the guns the protection of the shell plating and the coal in wing bunkers. The total complement is 286 men.

The machinery consists of two sets of four-cylinder triple-expansion engines, each set having four cranks balanced on the Yarrow, Schlick and Tweedy system. The two sets are designed to give a total collective indicated horsepower of 17,000, with a working pressure of 250 pounds per square inch at the engines and 280 pounds at the boilers. The cylinders of the main engines are carried on cast-iron "A" columns at the back and pol-

ished-steel columns at the front, the whole being supported on a cast-steel bedplate. The propellers are of the usual Admiralty type, with three detachable blades, the blades and boss being of bronze. The boilers, which are of the Vickers express type, are twelve in number, arranged in three separate watertight compartments, to work under the closed stokehold system of forced draft, the fans for supplying the air being driven by steam engines of the enclosed type, arranged for forced lubrication.

The vessel is thoroughly equipped with all the usual auxiliary machinery; the electric-light machinery, evaporating and distilling plant, and steam-steering engine, being placed in a separate compartment, and aft of the main engine rooms.

**Sapphire.**—The *Sapphire*, launched March 17th, is a third-class cruiser of the latest type, specially designed to obtain a high rate of speed on a moderate horsepower. Her dimensions are 360 feet by 40 feet by 21 feet, the displacement being 3,000 tons on a draught of 14½ feet. She is fitted fore and aft with a protective deck 2 inches thick, under which the boilers, engines and steering gear are placed. In a capacious poop accommodation is fitted for the captain and officers of the ship, together with ward room. The crew is berthed in the forecastle and in the 'tween decks, both of which are large and well ventilated. The magazines are placed underneath the protective deck, and consequently below water line. The armament of the vessel comprises twelve 4-inch guns, ten of which are placed on the upper deck; the foremost pair and the aftermost pair are capable of fore-and-aft fire. On the forecastle and on the poop are the usual bow and stern chasers. There are eight 3-pounders, four of which are placed on the upper deck amidships, and two are in the forecastle and in the stern, to be used as bow and stern chasers. Two above-water torpedo tubes are fitted on the upper deck. On the forecastle deck there is an armored conning tower of nickel-steel, 3 inches thick, from which the maneuvering of the ship is controlled. There are also the usual navigating bridge and searchlight platforms.

The vessel has three funnels and two schooner-rigged masts fitted with semaphore signaling and spar for wireless telegraphy.

She will carry nine boats, including a 32-foot steam cutter. The vessel is to be fitted with twin-screw engines, each having four cylinders, capable of developing 9,800 horsepower, and there will be ten boilers of the Reed water-tube type.

The sister vessels to the *Sapphire* now under construction are the *Amethyst* at Elswick (for turbine machinery) and the *Topaze* and *Diamond* at Birkenhead.—"Engineering," April 1, 1904.

**Topaze.**—Protected cruiser, third class. Building by Laird and Cammell, 3,000 tons, 9,800 indicated horsepower, 21¾ knots, has commenced her preliminary trials.

**Widgeon.**—A trial was made of H. M. S. *Widgeon*, a twin-screw shallow-draught gunboat built by Yarrow & Co., of Poplar, to the order of the Admiralty. The vessel has been designed especially for operations in shallow water, and is fitted with a device which has been introduced by Yarrow and Co. to enable efficiency, in regard to propulsive effort and speed, to be obtained with various conditions of lading. The twin screws are placed in tunnels aft, in the manner already adopted in similar craft constructed for the government by this firm. These tunnels consist of inverted troughs raised in the skin plating of the after part of the hull, the floor of the latter being very flat in order to secure the shallow draught. The crown of the tunnel is considerably higher than the water level, and as the propeller blades in revolving come within mere clearance distance of the top of the tunnel it will be evident that a considerable part of the propeller is also above the water level. The tunnel, however, dips below the surface all round—that is, its edges are under water. When the screws are caused to revolve, they drive the air out of the tunnels and the water, rising to fill the vacuum thus caused, causes the screws to be fully immersed. For this action to take place, it is, of course, necessary that there should not be free access of air to the tunnel. If the lading, and consequent draught of water, were constant the arrangement would be satisfactory, but as it is necessary to provide for the lightest draught when the vessel is fully loaded, there is considerable retardation owing to the propeller race being thrown against the after slope of the tunnel. In order to overcome this defect, Yarrow and Co. have intro-

duced a hinged flap, which forms the back part of the tunnel. At deep draught this is completely raised, and it is lowered as the vessel comes up in the water owing to consumption of fuel and stores or from any other cause. In this way an unobstructed flow to the propeller race is obtained, and yet a vacuum is secured in the tunnel at any draught.

The trials yesterday were designed more especially to test the efficiency of the device, and were carried out in the estuary of the Thames. They consisted first of a six-hours' run at 11 knots and a two-hours' run at 13 knots. These two runs were made consecutively without a stop, the actual speeds being 11.030 knots and 13.058 knots respectively. The latter speed is remarkable, considering the draught was no more than 2 feet 8 inches. These runs were made with the flap up, the vessel being fully laden. An hours' run was then made with the flap down, the conditions in all other respects being as on the two-hours' trial. The speed came out at 12.218 knots. It will therefore be seen that by means of the flap the speed of the vessel on full draught was raised more than four-fifths of a knot over what it would have been under the old conditions.

The *Widgeon* is 160 feet long and 24 feet 6 inches wide, the depth of hull being 6 feet. For facility of transport she has been constructed in sections not exceeding 18 feet in length fore-and-aft, each section being capable of floating by itself. These sections are so arranged by means of deep floors, or low bulkheads, that they can be bolted together in the water, and the complete vessel thus be built up afloat. The machinery space is protected by chrome-steel armor of sufficient thickness to be bullet proof at a point-blank range of 20 yards. On the upper deck, there is an armored battery 78 feet long, also protected by hard steel armor. Here are mounted two 6-pounder quick-fire guns and four rifle caliber (.303) Maxim machine guns. There is also an armored conning tower forward.

The engines are of the compound condensing type, and the boilers are the Yarrow straight water-tube description. There are a steam windlass, with special warping arrangements for hauling up rapids, steam steering gear, and other auxiliaries.

**St. George.**—The first-class cruiser *St. George* has for the past twelve months been undergoing a complete overhaul of hull and machinery at the hands of Workman, Clark & Co. The *St. George* is a comparatively new cruiser of the *Crescent* class, having been built in 1892. She is about 380 feet long over all, with a displacement of 7,700 tons. The engines are capable of developing an indicated horsepower of 10,000 under natural draft, and 12,000 under forced draft, and steam is supplied by four double-ended and one singe-ended cylindrical multitubular boilers. The protective deck extends all fore and aft, with extra armor-plating over the cylinders. The armament consists of two 9.2-inch guns, ten 6-inch guns and twenty-four smaller guns. She has also submerged torpedo tubes. The crew numbers 550, including officers. The overhaul has extended to the minutest details, and, in addition, there has been an entirely new electric installation fitted throughout, including motors for ammunition hoists. A new office and fittings for wireless telegraphy have also been fitted. The *St. George* had successful speed trials, in which she maintained a speed of 21 knots under natural draft for eight hours, the engines and boilers working smoothly throughout. This is in excess of any speed previously attained by the vessel.

**Terrible.**—This cruiser has undergone an overhaul at John Brown & Co.'s yard at Clydebank. Her additions are four 6-inch guns in casemates on the upper deck amidships, two port and two starboard. Her armament is now two 9.2-inch breech-loading guns in barbettes, fore-and-aft; sixteen 6-inch quick-firing guns; fourteen 12-pounder guns; eight 3-pounder guns; two .303 Maxims, and four submerged torpedo tubes.

**Cherwell.**—Torpedo-boat destroyer, 550 tons, built by Palmer, Jarrow-on-Tyne, has concluded her official trials. Speed, 25¼ knots; 7,100 I.H.P.; coal consumption, 2.33 pounds per H.P. hour; radius of action with 130 tons coal supply, 460 miles under forced draft. On the four-hours' trial 7,200 H.P. was developed with 358 revolutions. Speed, 25.6.

**Usk.**—Torpedo boat destroyer, 550 tons, has carried out her preliminary trials at Chatham.

**Welland.**—H. M. torpedo-boat destroyer *Welland*, the fourth of six destroyers of the new type being built by Yarrow & Co., Poplar, for the British Admiralty, was successfully launched April 14th. The dimensions of these vessels are as follows: Length, 225 feet; beam, 23 feet 6 inches. They are fitted with four-cylinder triple-compound engines and four Yarrow boilers. The engines of these vessels are balanced on the Yarrow, Schlick & Tweedy system.

**New Submarines.**—Vickers, Sons and Maxim, Barrow-in-Furness, launched March 3d, two more submarines for the British Admiralty. It is probable that another six will be put into the water by the end of the next four or six weeks. One submarine in course of construction at Barrow is of new design, and is being built under the supervision of Captain Bacon. This vessel contains many improvements suggested by recent experiments, and it is expected that the ten submarines in this year's estimates will be of this type.

**Submarine A-1.**—The court of inquiry into the circumstances attending the foundering of submarine A-1 will no doubt elucidate many points which were not fully brought out at the inquest. Data will probably be furnished which may prove to be of considerable value in directing the future operations of submarines, but as the deliberations of the court are held with closed doors, none of the facts elicited will be made known to the public. Everything associated with the condition of A-1 is kept strictly private to such an extent that passers by are not allowed to linger near the dock, but are requested by the police stationed there to pass on. However, from what can be gathered, it appears that the interior electrical arrangements have not been injured. Indeed, from what was stated at the inquest, they would seem to be in perfect working order. Looking at the submarine from the dockhead as she now lies high and dry, one can see very little damage. There is a bulge in the plating on the starboard quarter, but it is not known if this was caused at the time of the accident or later. The only other noticeable injury is in the base of the conning tower, where a hole is visible, but this is supposed to have been made during the process of

raising her. The absolute damage, therefore, caused by the collision must have been confined to the top of the conning tower. It is expected that A-1 will be moved during this week to No. 5 dock, a smaller one than that in which she now lies, and therefore more suitable for executing repairs to small vessels.

**Vigilant.**—Information was received at Devonport Dockyard of an accident on board the *Vigilant*, torpedo-boat destroyer, which was on her way from Sheerness to the western port. A crew had been sent from Devonport to navigate the vessel to the port where she was to be commissioned. The tubes of two boilers burst, and it was thought desirable to anchor. The *Vigilant* was able to proceed under her own steam.

**Run of Cruiser Squadron.**—With reference to the recent run home of the Cruiser Squadron, when it returned from Bermuda, at an average speed of about 16 knots, it appears to be the general opinion in the engineering departments that it would be advisable that such a cruise should be more often adopted, and that the ships would be in a more efficient condition, should a sudden emergency arise, if the rate of speed in squadron cruising were increased to 15 knots instead of the usual 12, the latter being insufficient to bring out any latent defects which might appear when the engines have worked at a greater number of revolutions. A speed of 15 knots, it is held, would better enable the engine-room staff to cope with such faults, as they would be prepared for them and be in the position to know when to expect them. Against this must, of course, be considered the increased consumption of coal which the extra speed would require; but, as the main object of a cruiser squadron is to move swiftly *en masse* from one point to another, the extra expenditure of coal would not be a total loss, if balanced by increased efficiency. During the recent cruise of the squadron the *Drake* and *Good Hope* proved themselves very efficient, the run from Jamaica to Bermuda being made for the first 24 hours with two-fifths power at 18 knots, the second 24 with three-fifths at 22.6, both ships keeping up almost the same speed; but in the last two hours, with four-fifths power, the *Good Hope* fell out of the

race, owing to a hot bearing, while the speed of the *Drake* was 23.5 knots.

**Oil Fuel on Battleships.**—The new battleship *Hibernia* is to be especially fitted for the storage of oil fuel in very large quantities, and her sister ships, the *Britannia* and *Africa*, will undoubtedly be arranged in the same fashion. The *Hibernia* is to have the whole of her double-bottom space fitted with storage tanks, and the suggestion has been raised as to whether coal firing will not be altogether abolished in the three latest additions to the *King Edward VII* class. An official gives his opinion that oil fuel will long remain merely supplementary to coal firing in warships. He admits that the method of employing it will very soon be developed to a stage at which it will prove quite as effective as coal for generating power. Notwithstanding this the coal bunker is not likely to become a thing of the past in warships for a long time to come. One point which, in the expert view, seriously militates against the general adoption of the oil fuel for warship purposes is its dangerously inflammable quality. An example of this was cited by a Construction Department official. Some time ago, when the German battleship *Kaiser Wilhelm II*, was carrying out steaming trials, she touched a rock with sufficient force to perforate her bilge plating amidships. An inrush of water followed, with the oil stored in the fuel tanks. Had this reached the level of the furnace doors, both boiler and engine-rooms would have burst into flame. Luckily the pumps proved equal to keeping the leak under control.

**Floating Coal Depot.**—(In addition to the brief note of the last issue.)—Swan, Hunter and Wigham Richardson, have launched from their Wallsend yard the first floating coal depot, built to the order of the Lords of the Admiralty. The depot is the first of its kind constructed on the Tyne. It is 424 feet long and 67 feet 9 inches in breadth. The boilers and connecting-pipes have been supplied by the Wallsend Slipway Company; the electrical plant by Clark and Stansfield; and the ventilation plant by Meachan and Co. of Glasgow. The depot will be stationed at Portsmouth. The depot is of 12,000 tons storage capacity—11,000 tons in hoppers and 1,000 tons in bags—and is

equipped with twelve Temperley transporters, worked by electric machinery; and the hoppers are fitted with eighty coal chutes for filling the bags without shoveling. The difficulty hitherto experienced of getting Welsh steam coal in hoppers to run or flow through the openings in the bottom or sides thereof, owing to the large lumps of coal bridging over and blocking the openings when under pressure, is solved by the new system.

The hull of the depot is in the form of a large flat-bottomed straight-sided vessel, with bluff rounded ends, and it is subdivided into seven compartments. The five middle compartments contain the ten hoppers; the after end compartment contains the electric generating machinery, and the forward end compartment is appropriated to crew accommodation and stores. Two longitudinal bulkheads, 9 feet apart, in the middle of the vessel, divide the five holds into ten hoppers, and form a clear passageway between them, giving access through the numerous openings to the space under the hoppers, and providing a clear exit up through which the bags of coal are hoisted by the transporters at any point in the length of the depot. The bottom of the coal hoppers is raised above the floors of the vessel, and provided with 240 trap-doors and 80 movable chutes, for tapping the coal from below into bags without shoveling, the flow of coal being regulated by means of grates worked by hand levers. The coal dust arising at the chutes is drawn off through a system of exhaust-air tubes, and delivered back in the hoppers. The Temperley transporters, for loading and discharging the vessel, are carried on four traveling towers, which run on the deck of the depot. The transporters have an overreach of 20 feet beyond the side of the depot, and lift their loads to a point 33 feet above water level. Each tower carries three transporters, two of which are inclined, and may be used for loading the depot from a collier, or for coaling a war vessel from the depot; the other is horizontal, and long enough to reach from the hatchway of a collier on one side of the vessel to the deck of a war vessel on the other. The output capacity of the depot is at least 500 tons per hour.—"Engineering."

FRANCE.

**Démocratie.**—Launched at Brest, April 30. This battleship is the third of the 1903 class; the two preceding, *République* and *Patrie*, were built at Brest and La Seyne respectively. Three others are still building, the *Liberté Vérité* and *Justice*. The principal dimensions are: Length, 442.9 feet; beam, 74.6 feet; draught, 27.5 feet; displacement, 14,900 tons; 18,000 horsepower; speed, 18 knots.

The armament has been modified from the preceding vessels of her type and is now as follows: Four guns of 12 inches, in two turrets, forward and aft; ten of 7.64 inches, of which six are in turrets and four in armored casemates on the deck beneath; twenty-six of 47 mm. The 7.64-inch guns have the same disposition as the 6.46-inch guns of the *Suffren*, the number being the same and replacing the eighteen of the latter dimension on the *République*. It has been questioned whether the increase in caliber of these guns will compensate for the decrease in number.

While the above changes have been made in guns, the same number of torpedo tubes has been retained as on the *République:* two submerged, two above water under light armor, and one directly astern in an unarmored compartment.

The main propelling machinery consists of three vertical, triple-expansion, four-cylinder engines, to develop a total of 18,000 horsepower, which is expected to give a speed of 18 knots at 110 revolutions. The length of stroke is 45.27 inches, and the diameters of cylinders respectively 34.67 inches, 51.61 inches, and 77.22 inches. At 110 revolutions the piston speed in feet per second is 13.83. As originally designed, Belleville boilers were to be furnished, though it is not stated that they have been ordered. For the *Justice*, Niclausse boilers have been ordered.

The *Démocratie* compares favorably in armor and protection with the English types, *Formidable* and *Duncan*, while to find a battleship of superior armament the *King Edward VII* class must be considered, although their displacement is nearly 17,000 tons. Germany, upon a smaller displacement than the *Démocratie* and the English battleships, has the *Braunschweig* type of 13,200

tons, which approaches nearest to them. The Italian battleship *Regina-Elena*, while having less protection, has a more powerful battery and the speed of a cruiser, all of which is obtained upon a displacement of 12,600 tons. One of the faults shown in this design is a lack of freeboard. America shows a battleship type distinctly superior in power to the *Démocratie* or the *République* in the *Connecticut* class, of 16,200 tons and 19 knots, having good protection and a powerful armament of four 12-inch guns, eight 8-inch, twelve 7.5-inch and twenty 3-inch.

**Léon Gambetta.**—The first class armored cruiser *Léon Gambetta* left March 1 for her steam trials. When steaming at a speed of 19 knots she struck, without any warning, on an unknown pinnacle rock off the Black Rock group of islets, and sustained severe injuries. Her starboard propeller is broken, and her central one injured, while the central keel plate is torn away for nearly her whole length; there are two holes of over sixteen feet across in her hull, one forward and one aft, which have flooded her magazines, and there is a rent of about 24 feet long on her port side, the plating of her hull also being crushed in further aft. It is stated that the mishap occurred through her compasses not having been properly adjusted. The armored cruiser *Jeanne d'Arc* occupies the only suitable dock where the *Léon Gambetta* can be repaired, and she is, at great inconvenience, to be taken out to make room for the injured ship, the repairs to which, it is believed, will take some months.

It was thought that the propeller blades of the *Jules Ferry* or of the *Victor Hugo* might be used for the *Gambetta* to hasten the completion of the repairs; but it was found that these blades would not fit the propeller hubs of the *Gambetta*, because of the slightly different dimensions used by the different makers, and it was necessary to cast new blades. This is being used as a strong argument in favor of building all machinery parts absolutely interchangeable for vessels of the same type.

The *Léon Gambetta* is the first of the series which includes also the *Jules Ferry*, the *Victor Hugo*, the *Jules Michelet* and the *Ernest Renan*, of which three are launched, one just laid down, and the last recently ordered, which will differ from the others in certain

particulars in which experience has shown changes to be required.

Her length is 480 feet; beam, 70.2 feet; greatest draught, 26.9 feet; displacement, 12,550 tons; designed horsepower, 27,500; designed speed, 22 knots; triple screws; total coal capacity, 2,100 tons; expected radius of action at 10 knots, 12,000 miles.

The propelling machinery consists of three triple-expansion, four-cylinder engines with piston valves. Diameters of cylinders: H.P., 41.73 inches; I.P., 65.61 inches; L.P. (2), 69.13 inches. Length of stroke, 39.4 inches. Engines designed for 27,500 horsepower at 125 revolutions; piston speed, 13.66 feet per second.

The boilers are of the Niclausse large-tube type.

Total engine weights, 1,144.64 tons; boiler group without water, 197.41 tons, and with water, 268 tons; total weight of propelling machinery and boilers with water, 1,412.6 tons.

Armament, four 7.64-inch guns in two turrets forward and aft amidships, sixteen 6.46-inch guns, twenty-two 47-mm. guns, two 37-mm. guns, and two 65-mm. landing guns. The arrangement of the sixteen 6.46 inch guns is four in armored casemates firing two directly ahead and two directly astern, and twelve in pairs in six turrets arranged in hexagon on the spar deck.

There are five torpedo tubes, two under water and three above water, two being under the forward armor and one firing directly aft.

**Victor Hugo.**—Armored cruiser, first class, was launched March 30th, at Lorient, after thirteen months upon the ways. This relatively long period was partly due to the transfer of her construction material from Toulon, where she was to have been built, to Lorient. The *Victor Hugo* is of the same type as the *Leon Gambetta*. Length, 489 feet; beam, 70.2 feet; draught, 25.23 feet; displacement, 12,600 tons. Her propelling machinery consists of three vertical, independent engines of 27,500 combined I.H.P. for a designed speed of 22 knots. There are to be four smokepipes, about 70 feet in height. The boilers, all of which were installed on board before launching, are of the Belleville type, twenty-eight in number, divided in four independent groups.

The armament consists of four 7.64-inch guns in two midship turrets forward and aft; sixteen 6.46-inch guns, of which twelve are in pairs in barbettes and four in the casemate angles; twenty 47-mm. guns. There will be two under-water torpedo tubes and three above-water tubes, two forward and one directly aft.

**Jules Michelet.**—Immediately after the launch of the *Victor Hugo* the slips were cleared ready for the laying down of the sister ship *Jules Michelet*, which took place on April 3. The *Jules Michelet* was ordered to be laid down a year ago, but the year's delay will not affect greatly the length of time required to build her, as during the year great progress has been made with the building material, and her construction will be rapidly proceeded with. She will be launched next January and be completed by January, 1907. She is the fourth ship of the class, but she will differ slightly from her three predecessors. Her displacement will be 20 tons more, and her engines will develop an additional 1,500 horsepower. No change in the guns has yet been decided upon, but it is suggested that instead of four 7.6-inch and sixteen 6.5-inch guns she should carry two 9.45-inch and twelve 6.5-inch guns.

**Condé.**—Again this armored cruiser has had an interruption in her trials. While under inspection, on April 7th, with a committee from Paris on board, it was found that an alarming quantity of salt water was entering through the main condensers. The trial was abandoned, and the *Condé* returned to port; her condensers must be modified to such an extent that it is thought that a month or more will be required before she is again ready to renew her trials.

Before the above inspection, however, her performance was very satisfactory. At reduced power, to determine coal consumption, 2,065 H.P. was maintained, burning 1.6 pounds of coal per horsepower hour, which gave a speed of 10.5 knots.

At this coal consumption, which amounts to 36 tons per day, the *Condé* would be able to steam 44 days on her total coal supply of 1,590 tons and cover about 11,000 knots. At her 14,000 H.P. trials she developed 13,632 H.P. and gave a mean speed of 19.6 knots, but, while it is stated that her Niclausse boilers and

the propelling machinery worked satisfactorily, the coal consumption is not stated.

**Jeanne d'Arc.**—The first-class armored cruiser *Jeanne d'Arc*, which has been now for some months in the dockyard at Brest, has recommenced her trials, but they have not been satisfactory. Among other modifications made while the ship was in dock, was the reducing of the size of her bilge keels, but she is still unable to do more than 22 knots, in place of the 23 for which she was designed, and her screws are again to be changed; she has no difficulty in maintaining a speed of 19 knots, and can pass rapidly from 10 to 15 knots and from 15 knots to 20, and as she has a large radius of action, is well protected and well armed, in spite of her failure to realize 23 knots, she is still a formidable and useful cruiser.

**Foudre.**—The torpedo depot ship *Foudre* has arrived at Cherbourg, where she is to be fitted to convey the two submarines, *Lynx* and *Protée*, to Saigon; it had been proposed to transport the two submarines by rail to Toulon, and embark them there, but the weight was found to be too great. It is said that it will be at least a month before the *Foudre* can be got ready to receive them, as her boilers are also to be thoroughly overhauled. She carries four second-class torpedo boats, 18 meters long, and of 18 knots speed, before the mainmast, and the cradles for carrying the submarines will have to be constructed on the after part of the deck. The *Foudre* will be employed for nine months on this service, and will make three trips. In the first trip, as already stated, she will take out the *Protée* and *Lynx*, from Cherbourg; she will then return to Toulon, and embark the submarines *Aigrette* and *Perle*, and returning to Cherbourg; she will, in the third trip, take out the submarines *Ludion* and *Naïade*. All six submarines are for Saigon.

**Suffren.**—On a recent run from Brest to Toulon, during a period of very heavy weather, this battleship was kept constantly under forced draft, burning 22.55 pounds to 24.60 pounds per square foot of grate per hour, without any distress to her Niclausse boiers.

The firing was regulated by the Merlu apparatus, which gave remarkable satisfaction.

**Torpedo Boats Nos. 278 to 294.**—Of these first-class torpedo boats, of 90 tons and about 26 knots speed, those from *No. 278* to *No. 294* will be ready for service during the present year. Certain of them have been very successful on their trials, *No. 280* giving the rather remarkable speed of 27 knots on 340 revolutions.

*Nos. 293* and *294* differ from the others, being fitted with turbine propelling machinery.

*No. 293*, launched from the Normand Works, Havre, will have five Parsons turbines, driving three shafts. Three turbines will be used for full power, one for reversing and one for "cruising" at a speed of about 14 knots. The boilers are of the Normand type, and the expected speed is about 24 knots on 1,800 I.H.P. Length, 129.6 feet; beam, 13.94 feet; draught, 4.10 feet.

*No. 294* is somewhat different in dimensions. Length, 126.3 feet; beam, 12.96 feet; draught, 5.7 feet; displacement about 97 tons. Her turbines will be of the Breguet type and her boilers the Du Temple-Guyot.

The boats to follow these numbers were not ordered until the end of last year, and will be of the first class, still further enlarged and better armed, with about 100 tons displacement, 2,000 I.H.P. and 26 knots speed.

**Dard and Balliste.**—These torpedo-boat destroyers have made 29.4 knots on their trials, a considerable advance over the contract requirements of 28 knots.

**Armored Cruisers.**—"Le Yacht" publishes an article on the more recent French armored cruisers, in which it states that from 1897 to 1900 vessels of this type were laid down almost exclusively in the French yards. Those now built, to the number of twelve, have cost about $50,000,000. They are analogous in their good qualities and in their faults. The latter are exaggerated in the smaller vessels, and the former are more evident in the larger vessels. The cruisers are of four types, namely, the *Jeanne d'Arc* of 11,200 tons; three of 7,740 tons of the *Dupleix* class; three of 9,517 tons of the *Gueydon* class and five of

10,014 tons of *Gloire* class. Compared with the ships of other countries the cruisers of the *Dupleix* and *Gueydon* classes are deficient in guns of large caliber, thus the *Dupleix* has nothing larger than her ten 6.5-inch guns, whereas the Russian cruiser *Bayan*, of about the same displacement, has two 8-inch guns in addition to ten of 6-inch, and the smaller Austrian cruiser *Karl VI* has two of 9.45-inch in addition to ten of 6-inch. The *Gueydon* has two 7.64-inch against the four 8-inch of the Japanese *Tokiwa* and the four 8.27-inch of the German *Friedrich Karl*, which are cruisers of only a few hundred tons greater displacement.

Generally speaking, the French guns are heavier than other guns in proportion to their caliber. They throw a lighter shell in order to obtain a high initial velocity, which is only of value at close quarters. The 7.64-inch guns of the *Gueydon*, and also those of the same caliber in use throughout the French service, are not quick-firing, though this is being remedied. The guns are badly distributed, the *Gueydon*, for instance, can only fire one 7.64 inch, two 6.5-inch and two 3.94-inch guns in the direction of her longitudinal axis; and the *Dupleix* only two 6.5-inch and two 3.94-inch. The broadside guns have a very limited horizontal field of action. Of the eight casemates of the 6.5-inch guns of the *Gueydon*, only two have protection continuous with the armor belt; the remaining six, therefore, are liable to be put out of action by a shell striking the unprotected part below them. The protection is continuous in the *Gloire* class below the casemates, but not between them.

The French cruisers, though armored, must not be expected on occasion to serve as battleships. With regard to their speed, the *Jeanne d'Arc* was built for 23 knots, but has only been able to make 21.75 knots; while the others can only attain with great difficulty the contract 21 knots, although the Belleville, Niclausse, or Normand boilers permit their engines to develop more than the contract power. When the ordinary bunkers are emptied the reserves of coal are difficult to get at, and it requires then more than a third of the crew to be at work in order to maintain a speed of more than 15 knots. The worst of all is

that the ships are not strongly enough built to withstand a full strain, and they are continually liable to break down in one part or the other.

JAPAN.

**New Japanese Battleships Katori and Kashima.**—A further advance in warship design and construction is to be exemplified in the two new powerful armorclads to be built in England, for the Japanese Navy, by Vickers' Sons & Maxim, of Barrow-in-Furness, and Sir W. G. Armstrong, Whitworth & Co., of Elswick, respectively.

In general design these ships will somewhat resemble the *King Edward VII* class, now in course of erection for the British Navy, with some important modifications and improvements. They will each measure 455 feet in length. This is 30 feet in excess of the recent battleships for the British Navy, but although an increase is made in the length there is no corresponding augmentation of the beam and draught, which are 78 feet 2 inches and 26 feet 7½ inches respectively. This increase of the length with the preservation of the other two dimensions marks a new feature in battleship design. That there are limitations to these dimensions is incontestable, for the progress and development of large battleships has outpaced the corresponding provisions of docks sufficiently large to accommodate them. There are few docks in existence capable of accommodating battleships exceeding 78 feet beam. Yet it is imperative in the case of hostilities when a vessel is injured that it should be able to be docked at the nearest port and the repairs effected with all possible celerity.

This fact has been borne forcibly in mind in the design of these two new vessels for the Japanese Navy. There are no graving docks in that country at present which could accommodate a vessel exceeding 78 feet beam. Consequently, the beam measurement has been minimized to the most advantageous extent.

The displacement of these vessels is approximately the same as the *King Edward* class—16,400 tons. The contracted speed is to be 18½ knots generated by twin-screw four-cylinder triple-expansion engines.

Steam is to be supplied from a battery of twenty Niclausse water-tube boilers. The coal capacity of each vessel is to be 2,000 tons.

The armament will be particularly formidable, comprising four 12-inch guns mounted in pairs within barbettes. The latter are to be built of 9-inch hardened steel and provided with armored hoods. In addition there will be one 10-inch gun placed in each of the four quarters in 6-inch armor, and also covered with protective hoods. In the *King Edward VII* class 9.2-inch guns are employed, but the substitution of the 10-inch guns instead of the 9.2-inch weapons accentuates the formidable character of the armament to a very considerable degree. The 9.2-inch gun fires a 380-pound shot with an energy of 20,000 foot-tons, while the 10-inch weapon discharges a 500-pound projectile with an energy of 28,000 foot-tons. A total of 2,000 pounds of shot with an aggregate energy of 112,000 foot-tons will thus be obtained from the four 10-inch weapons, as compared with 1,520 pounds of shot, and 80,000 foot-tons energy from the four 9.2-inch guns, an increase of 480 pounds and 32,000 foot-tons in shot and energy respectively.

The main armament will be supplemented by twelve 6-inch guns placed as follows: Five weapons on each broadside within the main battery and one on either side of the upper deck centrally situated.

For the repulsion of torpedo and submarine attack there will be twelve 12-pounder, three 3-pounder and six Maxim guns conveniently placed. Six submerged torpedo tubes are to be provided.

The guns placed behind the broadside armor will be separated by armor bulkheads. The 12-inch guns will be arranged 26 feet, the 10-inch guns 22 feet, and the main deck guns 14 feet above the load water line.

The scheme of protective belting first introduced upon the battleship *Mikasa* will be followed, but with some extension. For instance, the water-line belt will be 9 inches in thickness and 6 inches thick up to the level of the upper deck. In addition to this, however, a 4-inch continuous belting above the

lower or berth deck will be introduced for the first time. This addition will be continued to within 80 feet of the bow and 88 feet of the stern. By this arrangement, with the exception of right fore and aft, no part of the upper works of the ship will be left unprotected.

Both offensively and defensively these two vessels when completed will be the most powerful warships afloat. The gun power is the most formidable yet designed for a battleship, the guns being both heavier, and in the case of the 6-inch weapons more numerous than those decided upon for the vessels of other navies, and records a decisive advance in battleship construction and armament.—"Scientific American."

**Tsushima.**—The cruiser *Tsushima* (sister ship of the *Niitaka*) 3,420 tons, 9,500 H.P., whose Niclausse boilers were completely installed and regulated by Japanese workmen, was given her trial in February, her speed resulting in 20.6 knots instead of the 20 knots contracted for. Her piping system, which was constructed in Paris at the same time as the boilers, was entirely satisfactory without change, which gave her a gain in time of three months over the *Niitaka*, whose piping was constructed in the Japanese Government Building Yard. Both of these vessels are in Admiral Togo's squadron.

GERMANY.

**Prinz Friedrich Karl.**—The armored cruiser *Prinz Friedrich Karl*, in her trial at Wilhelmshaven, made 21 knots—17,000 I.H.P. She was constructed at the works of Blohm & Voss, Hamburg.

**Meteor**—(*ex-Ersatz Merkur*).—The fourth-class cruiser *Meteor* was launched March 26th at the Vulcan Works, Danzig; this is the first German man-of-war to be fitted with turbines. Mention was made of this vessel, page 360, February, 1904, JOURNAL.

ITALY.

**Regina-Elena.**—The battleship *Regina-Elena*, of the *Vittorio Emanuel III* class, of which five vessels are building, was launched at Spezia, April 28th. They are vessels of 12,625 tons; length, 435 feet; beam, 73 feet 6 inches; draught, 15 feet 10 inches. They have

10-inch armor on the belt and conning tower, 4-inch on the ends of the belt and the deck (reinforcing), 6-inch on the gun turrets, 3½-inch on the gun battery and lower deck bow. They are designed for 20,000 I.H.P. and 22 knots speed, and carry two 12-inch guns, twelve 8-inch, twelve 4-inch and twelve 3-pdrs., with four submerged torpedo tubes.

TURKEY.

**Medjidia.**—The Turkish cruiser *Medjidia* was launched last July and has been delivered. She was built for the Ottoman government, and is one of several vessels which the Wm. Cramp & Sons' S. and E. B. Co., have built for foreign navies. In 1900 Ahmed Pasha, chief engineer of the Ottoman navy, came to this country for the purpose of examining the American system of naval construction. As a result of his investigation the Turkish government contracted for the construction of the warship *Medjidia*, which is of the protected-cruiser type. The general dimensions and character of the vessel are as follows: Length on load water line, 330 feet; beam, extreme, 42 feet; draught, mean, 16 feet; displacement, 3,200 tons; speed, 22 knots.

The armament consists of two 6-inch rapid-fire guns, eight 4.7-inch rapid-fire guns, six 3-pounder rapid-fire guns, six 1-pounder rapid-fire guns, one 3-inch field gun and two torpedo tubes for 14-inch Whitehead torpedoes. The battery is capable of firing 584 pounds of projectiles at one round of all guns. Using the standard rate of firing for guns of smaller caliber, the total discharge of all guns in one minute would be 5,000 pounds. The maximum thickness of the protected deck over the space occupied by the engines and boilers is 4 inches. Otherwise the vessel is unarmored with the exception of the conning tower and tube leading to the protected deck. Each of the larger guns is protected with a shield for the protection of the crew. There is a strong ram at the bow, strengthened by the protected deck, which forms an integral part of the ram. The engines are two in number, of the inverted triple-expansion type, driving twin screws. The engines are capable of developing 12,000 H.P.; the boilers are of the improved Niclausse type.

**Abdul Hamid.**—The Turkish cruiser *Abdul Hamid* went through her speed and gunnery trials off the mouth of the Tyne. The vessel was built by Sir W. G. Armstrong, Whitworth & Co. to the designs of Mr. J. Perrett. She has a displacement of 3,700 tons, her length is 340 feet, and her beam is 47 feet 6 inches. She carries two 6-inch and eight 4.7 Q.F. guns, besides small guns and torpedo tubes. The engines were constructed by Hawthorn, Leslie & Co. A mean speed of 22.25 knots on six runs was realized over the measured mile. She also ran a six-hours' natural-draft trial, during which a speed of 21.1 knots was obtained. The machinery worked without a hitch. Each gun was satisfactorily fired at various degrees of elevation and training; a torpedo was also fired from the torpedo-tubes. The ship returned to the Tyne for final completion. The *Abdul Hamid* will leave shortly for the East, together with the new Imperial yacht *Erthogroal* built by the same firm.

## MERCHANT SHIPS.

**Dakota.**—The *Dakota* was launched at the yard of the Eastern Ship Building Co., February 6, and is intended for service between the Pacific terminus of the Great Northern Railway and the Orient. She is the largest vessel ever constructed in the United States. She is 630 feet long; 73 feet 6 inches beam; 56 feet to upper deck; 88 feet to captain's bridge, and 177 feet to top of mast. She has five continuous decks and four decks which are not continuous. She is rigged as a four-masted schooner with pole masts. The chief characteristic of the *Dakota* is her great strength. She is designed primarily for comfort and carrying capacity with a fair speed at low power.

Her framing is on the longitudinal system. The center girder is of box form, which gives her virtually two vertical keels instead of one. The girder is of the same depth as the double bottom, 6 feet. On each side of the girder there are several other vertical longitudinals. The double bottom is 6 feet deep for the greater part of its length, and is increased at the extreme ends where it merges into the fore and aft peaks at the collision bulkheads. The whole of this space can be filled with water when desired, to sink the ship to a suitable draught when making a voyage without a cargo. The plates are arranged to give a maximum strength, the riveting to the frames and to each other having received the utmost care. There is a continuous longitudinal bulkhead on the center extending from the inner bottom to the main deck.

A notable feature in the construction of this vessel is the distribution of the water ballast, by which various conditions of trim and safety can be obtained. The double bottom is divided longitudinally into three watertight divisions and transversely into about twelve, making in all thirty-six separate compartments. In addition to these there are the fore and after peak tanks and

side tanks about one quarter of the vessel's length from either end. The latter tanks are really fitted for the purpose of controlling the ship's stability and seaworthiness.

The vessel is divided transversely into thirteen watertight compartments, while the longitudinal bulkhead is watertight in the machinery space, which makes in all fifteen watertight compartments. The engine rooms are completely independent of each other; as are the boiler rooms, but access is had from one to the other by watertight doors. The coal bunkers are situated above the boilers and are so arranged that coal can gravitate direct to the stokehold floor. The method of pillaring is somewhat novel and has never been attempted before by any American shipbuilder. The *Dakota* has a deadweight carrying capacity of 20,000 tons. She has twin screws, and her engines are expected to develop 10,000 horsepower.

**Arrival of Oil-Burning American Steamship Nebraskan.**—The *Nebraskan*, American-Hawaiian S. S. Co., reached New York March 28th, having steamed from San Diego, Cal., using crude California oil in her boilers. The trip, via the Straits of Magellan, occupied 51 days, 7 hours and 27 minutes, at an average speed of 10.35 knots for the 12,724 nautical miles covered. One stop only was made, at Punta Arenas.

Her time for the distance is much better than that of her sister ship, the *Nevadan*, when she sailed for the Pacific, using coal only. The *Nevadan's* time was 62 days, including stops for coal. The voyage of the *Nebraskan* to San Francisco with coal was longer than that of the *Nevadan*. These two ships got their oil-burning equipment at San Francisco.

On her trip here the *Nebraskan* burned 9,300 barrels of oil. Her oil carrying capacity is 10,500 barrels. Most of this is stored between the double bottoms of the ship in what are called the reserve bunkers or tanks; the rest is stored in the main tank, extending from the bottom of the ship to the main deck. From the main tank the oil is pumped to the injection tubes and sprayed on the grates. The *Nebraskan* had no oil left in her reserve tanks, but has 1,200 barrels in her main tank, and has made this trip at less than half what it usually costs a freighter of her tonnage.

Her three furnace men do the work of twelve stokers. They attend to auxiliary engines that run the blowers and pump the oil from the main tank. The engine-room force does not differ materially from that of the ordinary freight steamship. The furnace men work in four-hour shifts, and their duties are pleasanter and not so hard as that of stokers.

She will return to the Pacific with her tanks filled with Texan oil, which is much like the oil she burned on her way here. She is 4,408 gross and 2,824 net tons, built in 1903.

**Wolvin, Augustus B.**—The *Augustus B. Wolvin*, the largest vessel ever built to navigate fresh water, was launched from the Lorain yard of the American Shipbuilding Company on April 9. There are very few ocean vessels that are purely freight vessels that exceed her in dimensions, her length being 560 feet over all and 540 feet on keel, while the beam molded is 56 feet at the widest part, and a molded depth of 32 feet amidships.

In the design are several new features, the principal one of which is the shape of the cargo hold. This is built in hopper form with sides sloping from the main deck to the tank top and ends built of like slope. This hopper extends 409 feet without bulkheads or divisions, and measures at the top 43 feet and at the bottom 24 feet. The space between the sides of the ship and the sides of the hopper is used for water ballast, so that the water ballast, as well as being in the usual double bottom underneath the hopper, extends up the sides to the height of the main deck stringer.

The ordinary hold stanchions are dispensed with, and in their place a system of girder arches is substituted to support the upper deck as well as the sides of the vessel. There are thirty-three cargo hatchways on the spar deck, each 33 feet by 9 feet in the clear, and spaced 12 feet apart centers, so that it will be possible to unload the vessel entirely without any hand shoveling. These hatchways are fitted with a patented system of steel-plate sliding hatch covers, operated by steam engines and shafting, so that so manual labor is required for the opening and closing of the hatch covers.

The water-ballast space is divided into numerous compart-

ments by watertight athwartship bulkheads fitted at intervals of about 60 feet, and the total ballast capacity is about 8,000 tons of water. The cubical capacity in the cargo hold of this immense vessel is about 500,000 cubic feet, which is equal to 401,000 bushels of grain, or to 12,500 tons of coal. On the spar deck are six 8-inch by 10-inch single-drum engines, carrying each a steel wire mooring line for the usual mooring and warping purposes. In fact, steam has been used wherever possible to displace manual labor. There is a steam windlass fitted for handling the two 8,000-pound stockless anchors, and a steam capstan on the spar deck aft. The ship will be fully equipped with electric lights throughout and has duplicate plants, so that there will always be one to fall back on in case of the other giving out.

| | |
|---|---|
| Length over all, feet | 560 |
| keel, feet | 540 |
| Beam, feet | 56 |
| Depth, feet | 32 |
| Load draught, forward and aft, feet | 21 |
| Ballast, fresh water, short tons | 8,000 |
| Cargo capacity, cubic feet | 500,000 |
| Dead weight, carrying, short tons | 12,700 |
| Coal bunker, tons | 350 |
| Engine: Number | 1 |
| type | quadruple. |
| cylinder, diameter, inches | 18½, 28½, 43½, 66 |
| stroke, inches | 42 |
| R.P.M., designed | 80 |
| I.H.P. | 2,000 |
| crank shaft, diameter, inches | 12½ |
| Propeller: Diameter, feet and inches | 14- 6 |
| pitch, feet and inches | 14- 6 |
| area, projected, square feet | 61.64 |
| Boilers: Number of | 2 |
| type | Babcock and Wilcox water tube. |
| working pressure, pounds | 250 |
| tubes, size, inches | 4 |
| steam drums, each | 1 |
| mechanical stokers | Duluth. |
| H.S., two boilers, square feet | 5,500 |
| G.S., two boilers, square feet | 150 |
| induced draft | Ellis & Eaves. |

The propelling machinery, as is usual in lake vessels, is located in the extreme after end of the boat. The main engine is of the quadruple, four-crank type, with cylinders 18½ inches, 28½ inches, 43½ inches and 66 inches in diameter, each having 42-inch stroke of pistons, and they are designed for an indicated horsepower of 2,000 when making 80 revolutions per minute. The cylinders are arranged from forward in the following order: High-pressure, first-intermediate, second-intermediate and low-pressure. The high-pressure is fitted with a liner secured in the usual way. The valves of the high, first and second-intermediate are of the piston type, placed in front of their respective cylinders, and driven by "Joy" radial valve gear. The low-pressure cylinder is fitted with a double-ported slide valve on the after end, operated by double-bar Stephenson link motion. The bed plate is of the girder type, of box section, in two pieces, bolted together, and has five main bearings lined with white metal. There are four back and five front columns, the former acting as guides for the crossheads. The piston rods are of steel 5⅝ inches diameter, and the connecting rods of hammered iron 9 feet long between centers, with wedge adjustment at top, and "T" ends with bolts at bottom. The crossheads are of cast steel, keyed to piston rods and fitted with steel crosshead pins, secured with double taper and nut. The slippers are of bronze, of large surface and easily adjustable. The crank shaft, which with its four cranks is built without couplings, is 12½ inches diameter. The crank pins are each 12½ inches diameter by 13½ inches long. The thrust is of the "horseshoe type" with six go-ahead collars and five backing. The engine is fitted with a direct-acting steam, and a hand, worm reversing gear, also a steam turning gear at aft end of thrust shaft. The propeller is four-bladed cast steel, of sectional type. The outboard bearing is 13 inches diameter by 4 feet 8 inches long, filled with lignum vitæ.

The boilers, two in number, are of the Babcock & Wilcox type, and are placed with a 12-foot space between them, to fire athwartships. The working pressure is 250 pounds per square inch. The steam is superheated, the superheater being placed on top of boiler proper. The boilers are fitted with the mechanical

stoker built by the Duluth Stoker Company, the coal being fed into hoppers, passing from thence on to traveling grates, the ashes being deposited at the back of the boilers and discharged overboard by means of steam-driven elevators. The boilers are fitted with Ellis and Eaves induced draft, having two 7 feet 6 inches diameter fans driven by double 6-inch by 5-inch high-speed engines.

To purify and heat the feed water before reaching the boilers, two Learmouth purifiers are fitted, also a large heater into which all the auxiliaries exhaust. There are the following auxiliaries in the engine room, the pumps, all being of the Blake type: One vertical cross-compound simplex air pump; two horizontal cross-compound simplex ballast pumps; one horizontal compound duplex feed pump; one horizontal duplex pony pump; one horizontal duplex bilge pump; one horizontal duplex cooler pump. Two General Electric generating sets of 15-kw. capacity each for electric lighting. One Globe steam steerer, and one Sturtevant fan with attached engine for ventilating purposes.

The coal bunker is fitted in front of the boiler room, and has capacity for about 350 tons of coal. In every respect the vessel has been fitted out and built to meet the most modern requirements of the Lake service.

**Sahara.**—The *Sahara*, the second largest carrier on the lakes was launched by the American Ship Building Co. from its Lorain yard. The *Sahara* is 494 feet over all, 474 feet keel, 52 feet beam and 29 feet deep, with a 5-foot water bottom. She has twenty-eight steel hatches, spaced 12-foot centers, removed and placed by the Brosseau device. The novelty in the construction of the *Sahara* rests in the substitution of the arch girder plate for stanchions. These girder plates are fastened athwarship between the hatches to web frames. This system of internal construction is intended to facilitate the loading and unloading of the vessel since it forms a continuous hold unobstructed by stringers or stanchions. The *Sahara* is equipped with a triple-expansion engine, 22½, 36 and 60-inch cylinder diameters by stroke of 42 inches, supplied by steam from two Scotch boilers, 13 feet 9 inches by 11 feet 6 inches, equipped with Ellis & Eaves draft. She has been chartered for coal for her maiden trip by

the Northwestern Fuel Co. It is intended to put 10,000 tons aboard her, if possible.

The keel for the *Sahara* was laid March 1; she was launched May 5, and three weeks hence it is expected that she will have her machinery and boilers installed and will be ready to go into commission. In other words, not quite three months will have elapsed from the laying of the keel until the vessel is actually in commission.

**Antrim.**—This first of the new vessels for the Irish service of the Midland Railway Company, was launched by John Brown & Company, Clydebank, last month. The company decided to build four steamers, of which all the hulls are alike, but the machinery different. Two will be fitted with reciprocating engines having cylinders of 23 inches, 36 inches and 42 inches in diameter, with a stroke of 30 inches; while in the other two vessels steam turbines of the Parsons type are to be installed. One single-ended and two double-ended boilers will be fitted, employing forced draft generated by electric fans. The length of water line is 330 feet; breadth (molded), 42 feet; depth (molded) to the upper deck, 18 feet, and to the promenade deck, 25 feet 6 inches. Eight watertight bulkheads divide the ship into compartments, and in addition to the double bottom there will be four decks. It is anticipated that the speed of these vessels under normal conditions will be 20 knots.

**Victorian.**—The Allan Line expects to place its new turbine steamer *Victorian* in the Atlantic service between Montreal and Liverpool next August. The *Victorian* will be the first turbine steamship to be engaged regularly in the North Atlantic trade, and will be by far the largest as well as the swiftest of the Allan fleet. Undoubtedly the Allan Line believes the turbine system to have passed beyond the experimental stage to assured success, otherwise they would not hazard the great sum involved in the construction of a modern liner.

The shafting of the *Victorian* has been specially designed for the requirements of ocean and island navigation, and consists of three shafts with one propeller on each, the high-pressure engine driving the center propeller while the low-pressures are attached to the outside shafts.

**Princess Maud.**—The steamer *Princess Maud*, launched at Dumbarton by William Denny & Bros., is the first turbine steamer built for the Irish cross-channel service. Her principal dimensions are: Length, 300 feet; breadth, 40 feet; depth, 24 feet 6 inches to promenade deck. To facilitate handling in harbor she has rudders both aft and forward. The stern rudder, which is of the balanced type, is specially designed by the builders for their turbine steamers, and is controlled from the flying bridge by a telemotor. The forward rudder is also controlled from the flying bridge. The propelling machinery consists of three sets of turbines by the Parsons Marine Steam Turbine Co., supplied with steam by boilers constructed by Denny & Co., Dumbarton.

**Turbinia.**—The Turbine Steamship Co. expects to have its turbine steamer in operation between Hamilton and Toronto by June next. She is now being built by Hawthorn, Leslie & Co., at Hebburn-on-Tyne, who were the designers of the British torpedo boat *Viper*, which attained the extraordinary speed of 37 knots an hour. The owners have fully recognized the possibility of turbine boats for passenger service on the lakes, and with the delivery of this new vessel, will inaugurate a new, quick service from Hamilton to Toronto. She will be Canadian-canal size, being 260 feet long, 35 feet beam and 20 feet 9 inches deep, with 1,200 tons displacement.

The engines of the new vessel will consist of three Parson's compound steam turbines, as follows: One high-pressure turbine on the center line and one low-pressure on either side. Each turbine will control an independent line of shafting, and there will be three propellers, one on each shaft. The reversing turbines, which will be of special size, will be incorporated in the low-pressure turbines to admit of the boat being worked astern. Steam will be supplied by two large cylindrical boilers. The propelling machinery will be capable of driving the vessel at a speed of about 21 miles an hour. There has been some question as to whether the turbine is adapted to short runs, with the necessity of frequently touching port, such as obtains on the runs on the great lakes, but it is quite clear that no trouble is expected on this score.

## YACHTS.

**Lorena.**—The steam yacht *Lorena* is the largest ocean-going turbine-propelled steam vessel afloat, and was built by Ramage & Ferguson, Leith, to the order of A. L. Barber, New York, from the designs and under the superintendence of Cox & King, naval architects, Pall Mall, London. The dimensions of the yacht are as follows: Length over all, 300 feet; length on load water line, 253 feet; breadth, molded, 33 feet 3 inches; depth, 20 feet 3 inches; tonnage (yacht measurement), about 1,406. The turbine-propelling machinery was supplied by the Parsons Marine Steam Turbine Company, Limited, Wallsend-on-Tyne, and consists of three independent Parsons compound steam turbines, viz: one high-pressure turbine and two low-pressure turbines, each turbine driving separate shaft, with one propeller on each shaft. Reversing turbines are incorporated in the exhaust casing of each of the low-pressure turbines, and the outer shafts are capable of being worked ahead or astern independently of each other, and of the high-pressure turbine, thus giving the vessel quick and powerful maneuvering power. Steam is supplied by four cylindrical boilers, working at a pressure of 180 pounds per square inch, and fitted with Howden's system of forced draft.

The fan and engine for forced draft to boilers is also fitted in the main cross bunker. The total length of the engine, boiler and bunker space collectively is about 106 feet, the bunker capacity being very ample, as the *Lorena* carries sufficient coal to enable her to steam about 5,000 miles at a speed of 13 knots per hour, or about 3,000 miles at a speed of 17 knots per hour.

The *Lorena* ran her official trial trip at Aberlady, in the Firth of Forth, when she ran five double runs in all on the measured mile. The first four runs were made at reduced speed, while

for the next three double runs the mean speed attained was 18.02 knots per hour. On the best run a speed of 19 knots per hour was obtained in slack water, the mean number of revolutions of the center shaft being about 550 per minute and of the wing shafts 700 per minute. The bearings revolve in oil, thus reducing friction to a minimum, and by an economical arrangement the oil is pumped from one end of the turbine to the other, the consumption of oil being only about 5 per cent. of that for reciprocating engines. The machinery was kept running at full speed for about five hours, and during the whole of this time worked with the utmost smoothness. A very noticeable point was the entire absence of vibration; a very desirable feature in a yacht. From observations taken on the trial trip, as also from data since obtained, it is found that this is a very economical vessel as regards coal consumption.

When the *Lorena* came from Brightlingsea to Southampton she made the passage at an average speed of 12.4 knots. Upon this occasion she only burned one ton of coal per hour, with all auxiliaries going. This speed was maintained on two boilers in the face of a foul tide and a fresh westerly gale from off Dungeness down to the Wight. This fact is of considerable interest to steam yachtsmen, as it shows that turbine engines can be run at a moderate speed with economical coal consumption.—"The Yachting World."

## OBITUARY.

It is with the keenest regret that the Council announces the loss sustained by the Society in the death of three of its members since the last issue of the JOURNAL.

Lieutenant Commander Edgar T. Warburton, U. S. N. Died on board U. S. S. *Maine*, April 1, 1904.

Lieutenant Henry K. Benham, U. S. N. Died at Key West, Fla., April 8, 1904.

Lieutenant Commander Edward R. Freeman, U. S. N. (Retired). Died at Holly Springs, Miss., April 24, 1904.

*ERRATA* to "EXPERIMENTS ON THE OUTFLOW OF STEAM."
Volume XVI, No. 2.

Page 568, line 11 from top, for "9 by 22.9" read "$9 \times 22.9$."
Page 569, line 2 from bottom, for "opening" read "openings."
Page 570, foot note; for "$t_5$ and $t_6$" read "$t_3$ and $t_4$."
Headings for the 8 tables, for "$^\circ C$" read "$^\circ C$."
Page 580, line 6 from bottom, for "$\frac{p_1}{p_2}$" read "$\frac{p_2}{p_1}$."
Page 583, line 7 from top, for "6.5774" read "0.5774."
Page 583, formula

$$w = \sqrt{\frac{2gk}{k-1} p_1 v_1 \left[ 1 - \left(\frac{p_2}{p_1}\right)^{\frac{k}{k-1}} \right]}$$

should read

$$w = \sqrt{\frac{2gk}{k-1} p_1 v_1 \left[ 1 - \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}} \right]}.$$

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*ERRATA* to "ON PORT AREAS FOR STEAM ENGINES."
Volume XVI, No. 2.

Page 604, line 5 from top, for "insuitable" read "unsuitable."
Page 606, line 14 from top, for "$\frac{F}{x_2'}$" read "$f_{x2}'$."
Page 609, at the head of columns 1 and 10, for "vH" read "per cent."

XU